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AN INVESTIGATION INTO THE REQUIRED EQUIPMENT AND PROCEDURES FOR THE ACCURATE MEASUREMENT OF PRESSURE IN HYDRAULIC FLUID POWER SYSTEMS

By: The Fluid Power Institute,
Milwaukee School of Engineering

May 27, 1976

Under Contract To

The U.S. Army Mobility Equipment

Research and Development Center,

Fort Belvoir, Virginia

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Report No. 5026

Jack L. Johnson, P.E.
Director, Fluid Power Institute
Project Manager

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FOREWORD

This investigation has been carried out by the Fluid Power Institute, Milwaukee School of Engineering under Contract #DAAC53-76-C-0036 with the U. S. Army Mobility Equipment Research and Development Center. It was augmented by an assignment to the United States Delegation from a special Working Group of the International Standards Organization.

AN INVESTIGATION INTO THE REQUIRED EQUIPMENT AND PROCEDURES FOR THE ACCURATE MEASUREMENT OF PRESSURE IN HYDRAULIC FLUID POWER SYSTEMS

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AN INVESTIGATION INTO THE REQUIRED EQUIPMENT AND PROCEDURES FOR THE ACCURATE MEASUREMENT OF PRESSURE IN HYDRAULIC FLUID POWER SYSTEMS

1.0 Introduction and Background

The definition of Fluid Power is: the generation, transmission, and control of power by means of a pressurized fluid. As the world's energy reserves dwindle, more attention must be given to conservation of energy, especially as can be achieved through more efficient transmission of power. An improvement of only 1% would result in the saving of millions of kilowatt-hours of the energy reserves, annually. Industry is now concentrating its resources on improved energy transmission through design of more efficient machines.

But, in order to assess its effectiveness in improving efficiency, industry must be supplied with the proper tools of measurement. In hydraulic fluid power systems, pressure is one of the parameters which reflects the level of power being transmitted. It is, therefore, essential that it be measured accurately in order to detect the improvements in efficiency. Until now, there has been no universally agreed to method for the accurate measurement of pressure in hydraulic fluid power systems.

There are a number and variety of industrial and government testing standards for hydraulic equipment, all of which call for the measurement of pressure. Rather than state the methods by which pressure is to be measured, these standards specify the ultimate accuracy which must be met by the testing agency.

After the Measurement Accuracy Survey conducted by the Milwaukee School of Engineering in 1973 under contract with the U.S. Army, it was concluded that there was no effective method to either prove or disprove a given accuracy claim. Furthermore, it was learned that although two different laboratories used similar techniques and instruments, their estimates of final accuracy may differ widely, sometimes as much as 50-to-1. There was lack of universal agreement on the interpretation of a given accuracy statement, differing opinions being offered as to percent of reading, percent of fall scale or percent of maximum measured value. It was also learned that the methods of tracing an instrument's calibration lineage to government recognized physical standards was not widely understood and even less widely used as a matter of standard procedure. But time and again, testing agencies expressed concern over the accuracy of their own measurements. They desired standards which would allow them to confidently conclude that their measurements would reasonably agree with other competent laboratories.

Several standards are being promulgated which deal with the instrument only, such as ISA's documents on potentiometric and strain gauge pressure transducers. These standards are essential, because they deal with terminology and characteristics and thus, assure their manufacturers that all competing devices enter the market place with uniform methods of specifying performance. Except as may be implied by the specifications, these standards do not deal with the specific methods necessary to acquire accurate data in their use.

At least one standard, SAE's ARP 24B, attempts to deal with the problems of the testing agency. This document specifies the design of the pressure tap, but it is not the complete answer because of three limitations:

A. It deals only with the tap and its placement in the circuit. It does not cover the multitude of other factors which affect the accuracy of pressure measurement.

B. Because of dimensional requirements, it is impractical on tube sites under 3/4 inch and unworkable on tube sizes below 1/2 inch.

C. Although it specifies the location of the tap relative to upstream and downstream flow disturbances, the recommendations are not consistent with current thinking at the international standards level.

An interesting aspect of "24B" is that it specified multiple holes in its tap design. As reported later, the use of multiple holes cannot be justified in the literature. As a matter of fact, the use of more than one tap hole raises the specter of unexpected measurement errors, because dissimilarity in their construction causes flow between the holes. To our knowledge, this effect has never been documented. Clearly, a standard which deals with the requirements for the accurate measurement of pressure is an idea whose time has come. The proposed standard which occupies Section 2.0 of this report, is a first attempt to fill that need. It enjoys an interesting history.

Prior to the January, 1973 Frankfurt meeting of ISO/TC-131/SC-8 (Fluid Power Testing Subcommittee), the United States adopted the position that accuracy statements in testing standards should be specified relative to the maximum measured value encountered in the measurement of particular parameter on a given component undergoing test. This position did not prevail. In fact, only Holland voted with the United States. All other delegations insisted that accuracy requirements be specified relative to the measured value-percent of reading.

By the time of the October, 1974 London meeting of ISO/TC-131/SC-8, the Milwaukee School of Engineering had conducted its Measurement Accuracy Survey of nearly 200 fluid power laboratories. Among other things, it led to the United States delegation insisting that standards be developed, when followed, would result in acceptably accurate measurements.

Additionally, it was insisted that measurement and accuracy requirements be removed from testing standards per se and placed into appropriate appendices. Both these views did prevail in London 1974, with SC-8 establishing Working Group 3 entitled "Errors and Classes of Accuracy". The Secretariat was awarded to the United States who subsequently elected Gary Roberts of Oklahoma State University as Chairman and Jack L. Johnson, Milwaukee School of Engineering as Delegate-Expert. Other participating nations were the United Kingdom, France, Italy, Holland, Russia, France, and Germany. The Working Group was charged with the development of proposals on the measurement of the key parameters of rotational speed, torque, flow, pressure, and fluid temperature.

In November, 1975, the Milwaukee School of Engineering was awarded a U.S. Army contract to "Develop a Draft Standard on the Measurement of Pressure". Less than one month later, during the first meeting of Working Group 3, the United States was given an assignment with exactly the same title. This report is the result of those two actions.

The first meeting of Working Group 3 produced two important decisions. First, its work would be restricted to measurements on parameters in their steady-states and second, proposals would outline those procedures, which when followed, would result in acceptably accurate measurements. The investigations reported herein were carried out under the full implications of those decisions.

The first section of this report details the investigations that were conducted in the quest for the proposed pressure measurement standard. Section 2 consists of the draft proposal itself.

A literature search was conducted, primarily to determine the extent of work done to establish the quality of tap holes and their quantities. The search led to the laboratory studies which were conducted on both improved (de-burred) and unimproved tap holes. Test velocities reached 70 feet per second.

It has also been widely accepted that non-symmetrical snubbers will produce pressure measurement errors when the pressure is pulsating. Computer simulation studies were carried out to assess the exact extent to which snubber characteristics offset pressure measurement accuracy.

In any practical measurement standard, the subject of a human observer's ability to read and interpret digits from an analog instrument is inevitable. To quantify that ability, several students were given analog interpolation tests to determine the statistical ability to resolve the position of a pointer against a dial face. The procedures are not detailed in Section 1, due to contractural scope and time pressures, however, Section 2 contains the essential results. On any analog read-out device, the pointer width and the separation distance between divisions interact to produce a "readability" of the instrument.

Section 2.6.0 proposes a method and a formula for quantifying an instrument's readability and thus limits its applicability. Further details will be presented at the 1976 Fluid Power Testing Symposium and the 1976 Conference of Fluid Power.

Section 2 consists of the proposed standard. It contains several key considerations:

Certification Lineage (Traceability)

Readout Characteristics

Working Instrument Requirements

Snubber Requirements

Tap Hole Quality

Tap Hole Quantity

Tap Hole Dimensions

Application Techniques .

1.1 Literature Search

1.1.1 Purpose

The basic purpose of the literature search was to determine the method of construction and location for the pressure taps to be used as references in the pulse-free tests.

A secondary purpose of the literature search was to find references as to the use of multiple holes in the construction of static pressure taps. (Piezometer rings)

1.1.2 Results

As the literature search was meant to be a cursory check of work already done, it did not go into great depth. However, it was found that most handbooks and textbooks referenced three basic works:

I. Hiram F. Mills, "Experiments Upon Piezometers used in Hydraulic Investigations", Proceedings, American Academy of Arts and Sciences, 1878.

II. Allen and Hooper, "Piezometer Investigation", Trans. ASME, Vol. 54, 1932, HYD.

III. R. E. Rayle, "Influence of Orifice Geometry on Static Pressure Measurements", ASME 59-A-234, 1959.

All three of the above papers went into great detail on their construction of the pressure taps, and the errors that could be expected due to variations in the tap configurations.

Some of the conclusions drawn in the papers are as follows:

Paper 2

1. The error of a Piezometer is a constant percentage of the local velocity head existing at the orifice.

2. The size of the opening in the pipe wall has no effect within the limits tested, which were from 1/16 inch to 27/32 inch opening with velocities up to 7.3 ft/sec in a 12 inch pipe.

3. A true square-edged orifice is accurate, but very sensitive to slight changes in construction and position.

4. A standard Piezometer plug on plate must be absolutely flush with the conduit wall.

5. A Piezometer that projects beyond the pipe-wall surface has a large negative error.

6. The burr must be carefully removed from a square-edged orifice.

7. A Piezometer plate or plug is not sensitive to minute abrasions on its surface.

8. A Piezometer orifice must continue with parallel sides for over 2 diameters into the plug before its shape is changed.

9. An orifice with a large radius of rounding has a small positive error.

10. An orifice with a 1/4 inch hole and 1/8 inch radius of rounding, is recommended for standard practice.

Paper 3

1. As the Piezometer tap hole size approaches zero, the static pressure error approaches zero.

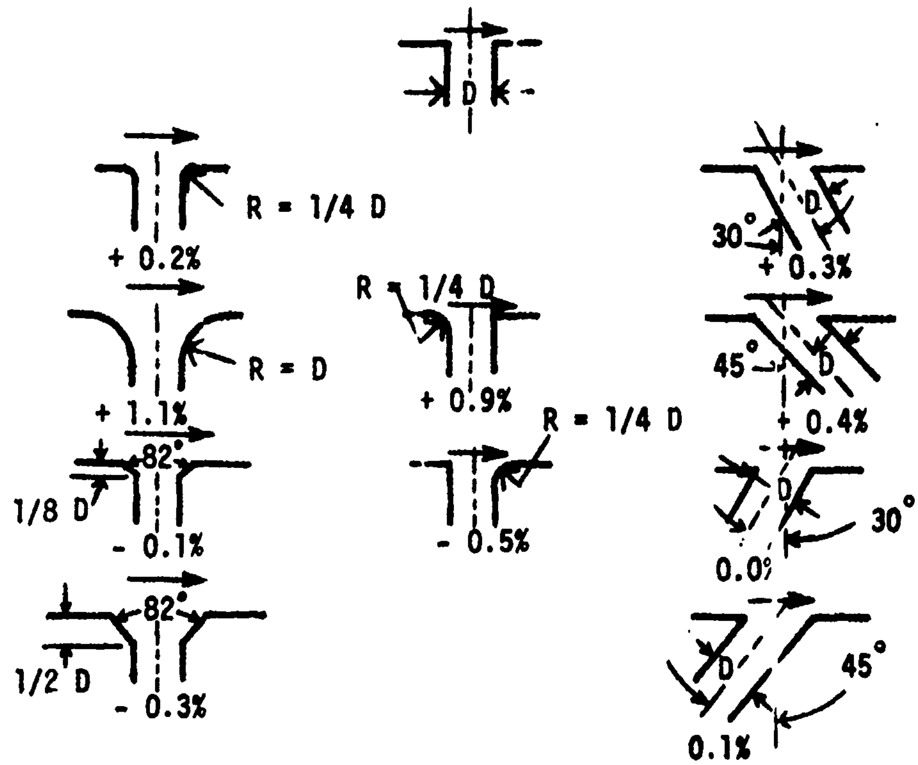
2. A .03 inch hole with a .015 inch deep counter ink should give nearly true static pressure, due to the counterbalancing effects of errors due to hole size and countersink shape.

3. Failure to remove any burrs resulting from drilling a hole will give negative errors of 15 to 20 per cent of the dynamic head.

4. Failure to completely remove the burr, when the burr can no longer be felt with the finger, but is a visibly brighter area, will give negative errors up to 2 per cent of the dynamic head.

5. Slight tapers at various places in walls of tubes thought to be straight can cause what appear to be erratic pressure drops along the length of a tube. A taper of 0.0006 in. per in. in a 1-in. section, reducing size in direction of flow, increased the local friction factor by 30 per cent, which is far greater than that resulting from pressure drop computed from Bernouilli's equation. Such errors can not be attributed to the orifice geometry, but to the geometry of the walls of the tube near the orifice.

6. Smoothing of the interior wall of a pressure tap with grinding compound should be done by machine rather than by hand, otherwise uneven walls produced can cause negative errors up to two per cent of the dynamic head. Sharp edge holes can best be produced by removing the burr in three or four steps, alternately working at the tap wall and the main bore wall, finishing with a final smoothing of the main bore.



Effect of orifice edge form on static-pressure measurements. Variation in per cent of dynamic head.

1.1.2 Conclusions

The work by the above authors was sufficient to establish a reference hole design that had the following qualties:

1. length/diameter ratio approximately equal to 2

2. inside surface of the pipe to be free of burrs, with a sharp, clean edge where the tap hole comes through

3. tap hole to be perpendicular to the center line of the pipe.

However, the literature search did not establish a basis for having multiple tap holes for a pressure pickup (Piezometer ring) other than it might be more "statistically correct".

All the work by the authors was performed at fluid velocities less than 10 feet per second. However, in modern fluid power systems, it is not uncommon to find fluid velocities in excess of 50 ft/second. Therefore, it became desirable to test at these higher velocities. The laboratory studies for this report carried out at velocities up to 70 ft/sec.

As to the location of the pressure taps in the piping, document number N96 of ISO/TC-131/SC-8 (component testing) "Method of Determining the Pressure Differential-Flow Characteristics of a Hydraulic Valve-Verification Experiment". It summarizes the work conducted at the National Engineering Laboratories, East Kilbride, Scotland, regarding tap placement.

The conclusion drawn in the above paper was that the tap location upstream or downstream from a flow disturbance is much more critical in the area of laminar flow than turbulent flow. Because all the lab tests were to be performed at Reynold's numbers in excess of 8500 (turbulent flow), it was decided that in this investigation, all lab tests would be conducted with a tap location of 10 diameters minimum downstream and 5 diameters minimum upstream from any disturbance.

1.2 Analytical Studies

A popular method for the damping of pressure pulsations in hydraulic pressure gauge circuits is to place a relatively restrictive orifice, called a snubber, in series with the gauge. This "hydraulic resistance" in series with the gauge and line "hydraulic capacitance", form a low frequency filter network resulting in a steady reading on the gauge which facilitates its reading. In some installations, the orifice may be fixed and permanently attached to the gauge. In laboratories, a variable orifice may be used so that the gauge-orifice network can be "tuned" to the system under test.

It is well-known that if the snubber does not have a symmetrical pressure-flow characteristic, that is, if it conducts flow better in one direction than in the other, then the ultimate gauge reading will be in error in the presence of pulsations. Until now, there has been no effort to assess the magnitude of this error.

This study was directed toward learning the error between the true mean pressure of a pulsating pressure source and the indicated value on a pressure gauge when using a "typical" variable snubber in series with the hydraulic capacitance of a "typical" pressure gauge. Toward that end, the forward and reverse pressure-flow characteristics were measured on an arbitrarily selected ¼ inch variable snubber valve for several snubber settings. Also, the pressure-volume characteristics were measured for three bourdon tube pressure gauges which were used to derive values for the non-linear gauge capacitance.

The orifice conductivity and gauge capacitance were then incorporated into a digital computer program simulating the dynamics of the circuit in order to assess the resulting error in the average pressure. To be considered were the following parameters:

- Orifice forward-reverse characteristics
- Peak-to-peak amplitude of pulsations
- True average pressure
- Value of capacitance
- Non-linear capacitance
- Pressure pulsation waveshape
- Error contribution

Although various waveshapes were not studied, it is felt that it would have little effect. None-the-less, a waveform generated and measured in an actual pump were used in the simulation. After analysis of the results, it was possible to formulate a single simple equation which relates the forward to reverse characteristics, (ρ), of the orifice to the indicated average pressure, the measured peak-to-peak value of the pulsations and the expected, or maximum allowable error contribution due to the snubber.

Also because it can affect the amplitude of the pulsations, effects of line lengths used to inter-connect instrument and tested system were investigated.

1.2.1 Bourbon Tube Gauge Measurement System

The snubbing orifice and bourdon tube pressure gauge form a dynamic pressure ripple damping system which can contribute to the error in measurement of the true average pressure in a system containing pressure pulsations. This section contains the details of the method by which the amount of error contributed by the snubber has been assessed. It begins with the laboratory measurement of snubber and gauge characteristics and goes on to explain the dynamic computer simulation.

1.2.1.1 Snubbing Orifice Studies

Purpose: To determine the forward and reverse pressure-flow characteristics of a "typical" snubber valve so that an equation could be derived for the computer simulation of section 1.2.1.3.

Procedure: The typical snubber valve chosen for the test was a ¼ inch needle valve made by Marsh Instrument Company. The forward direction of flow was chosen to be in agreement with the direction of the arrow, which was stamped on the side of the test valve. To determine the test valve opening angle, a pointer was attached to the handle and a plate marked in 5° increments was attached to the body, (see Figure 1.2.1.1.2). When the test valve was completely closed, zero was indicated on the plate by the pointer. A variable load was applied utilizing two valves, which were identical to the test valve. The two load valves were placed in series downstream of the test valve. The first load valve allowed coarse adjustment of the load, and the second load valve allowed fine adjustment.

For test valve opening positions of 25° and 30°, a calibrated 0-200 psid differential pressure gauge was placed in parallel with the test valve to indicate the differential pressure set points of 50 psid, 100 psid, 150 psid, and 200 psid. The differential pressure setpoints of 300 psid through 800 psid, in 100 psid increments, were obtained by calculating the difference between two calibrated 0-5000 psig pressure gauges. One pressure gauge was located upstream of the test valve and the other was located downstream of the test valve.

For test valve opening positions of 10° and 20°, the 0-200 psid differential pressure gauge was used to indicate the differential pressure set points of 50 psid, 100 psid, and 150 psid. The differential pressure set points of 200 psid through 800 psid, in 100 psid increments, were measured using the previously mentioned 0-5000 psid gauges located on either side of the test valve.

Flow rates were determined by measuring the time required to accumulate a predetermined volume within a graduate (see Figure 1.2.1.1.2).

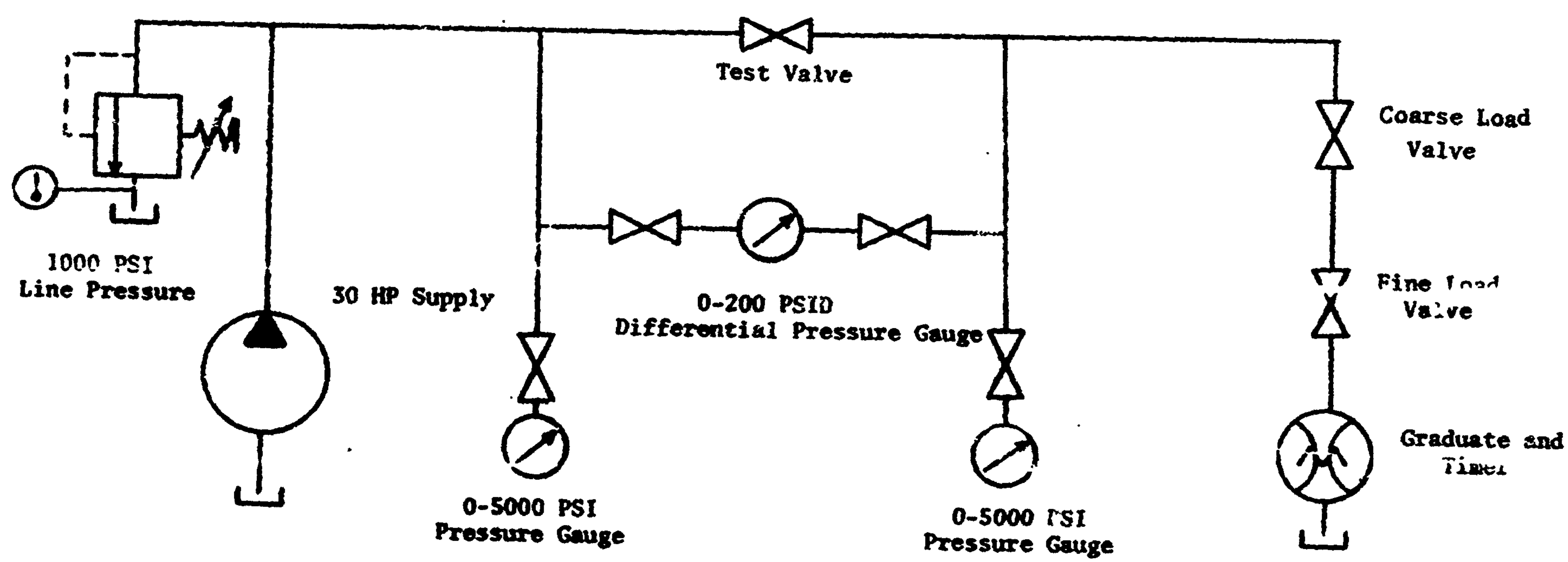
For the forward direction of flow, the load valves were closed, the test valve was opened to 40°, the pump was started, and the relief valve was adjusted to obtain a line pressure of 1000 psig. When both 0-5000 psig pressure gauges indicated 1000 psig, the test valve was adjusted to the 30° open position. The load valves were then opened until the proper differential pressure set point was obtained, the flow rate was then determined, using the afore mentioned volume-time measurements.

After the forward direction had been completed, the test valve was removed from the circuit, rotated 180°, without disturbing the test valve opening position of 30°, and reinstalled. The reverse flow rate at various differential set points was then obtained following the same procedure as used for determining the forward flow rates.

Test valve opening positions of 25°, 20°, and 10° were then tested in a similar manner. The only exception being that in the 25° and 10° open positions, the reverse flow rates were obtained before the forward flow rates.

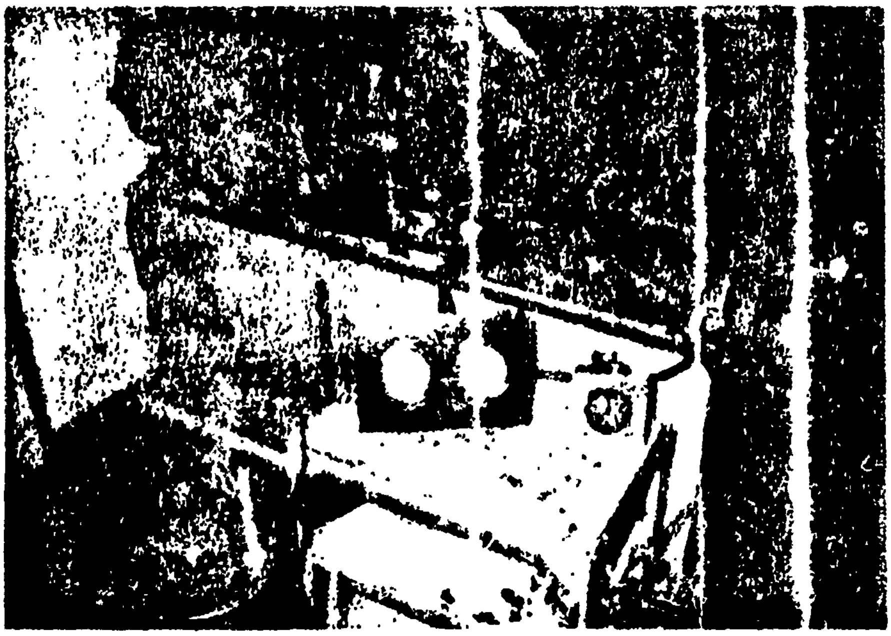
Hydraulic Schematic of Orifice Studies Test Setup

Figure 1.2.1.1.1

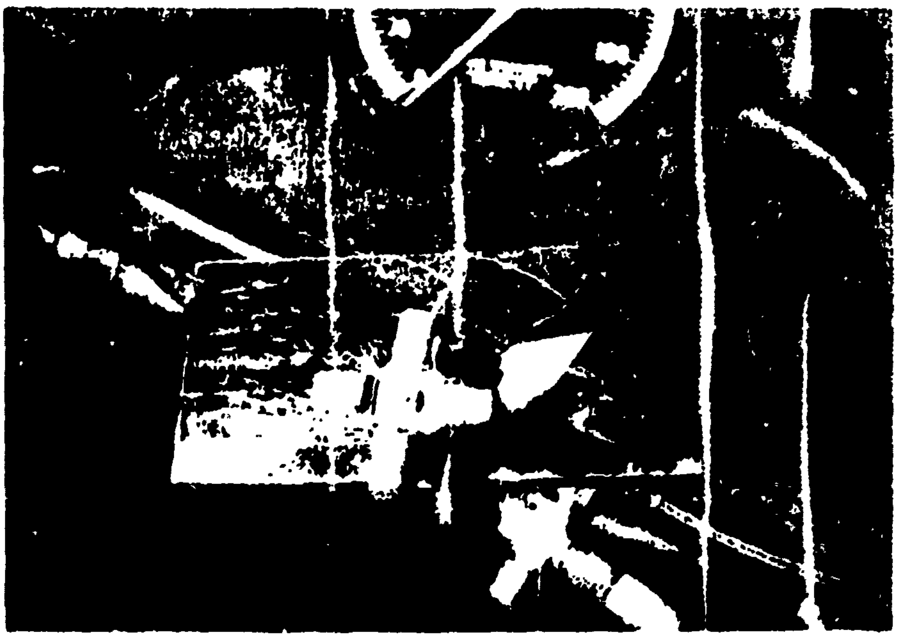


PHOTOGRAPHS OF TEST SET-UP

Figure 1.2.1.1.2



Test Set-Up



Test Valve Opening Angle Indicator

Instrumentation

Pressure Gauges

two Jos. P. Marsh Corporation type 100
0-500 psig in 50 psig increments

Differential Pressure Gauge

Greer Hydraulics 0-1500 maximum line pressure
0-200 psid in 1 psid increments

Timer (electrical stopwatch)

Standard Company
0-60 seconds in .01 second increments

Graduates

0-10 cc - Pyrex Student Line No. 3076
in 0.1 cc increments

10-100 cc - Nalgene
in 1.0 cc increments

20-150 cc - Nalgene
in 20 cc increments

Temperature Gauge

Weston
20°F to 240°F in 2°F increments

Data Table 1.2.1.1.1

Test: Determination of the forward and reverse pressure-flow characteristics of a snubber valve

Component: 1/4 inch Marsh Inst. Co. needle valve

Date: December 19, 1975

Technician: L.A.L.

PSID	10° Reverse Q(GPM)	10° Forward Q(GPM)	20° Reverse Q(GPM)	20° Forward Q(GPM)	25° Reverse Q(GPM)	25° Forward Q(GPM)	30° Reverse Q(GPM)	30° Forward Q(GPM)	
50	.00157	.00190	.0163	.0128	.0216	.0235	.0272	.0252	
100	.00297	.00386	.0290	.0231	.0377	.0405	.0572	0.477	ΔP gauge
150	.00472	.00570	.0391	.0338	.0561	.0484	.0837	.0706	
200	.00424	.00523	.0413	.0366	.0722	.0725	.114	.0974	
300	.00685	.00828	.0645	.0543	.0923	.102	.144	.132	
400	.00975	.0107	.0820	.0728	.126	.141	.208	.180	
500	.0124	.0156	.104	.0978	.164	.174	.254	.214	(2) gauge
600	.0154	.0198	.143	.125	.209	.216	.309	.256	
700	.0209	.0224	.176	.151	.259	.268	.402	.330	
800	.0246	.0275	.217	.180	.314	.288	.448	.388	

1.2.1.2 Gauge Pressure-Volume Study

Purpose: To determine the pressure-volume characteristics of a "typical" Bourdon tube pressure gauge so that an equation could be derived for hydraulic capacitance for the computer simulation of 1.2.1.3.

The test circuit was assembled as shown in the circuit schematic of Figure 1.2.1.21. The components and hardware were the same as those used on the downstream side of the orifice of the orifice study, 1.2.1.1; except for a higher pressure rating of the plate used in the Pace differential pressure transducer (instrument 6) and a different "T" on the supply pump.

The test gauges were filled with oil, then installed in the test circuit and the system was bled of any remaining air. The large face gauge (instrument 1) was the only test gauge that had a bleed tap at the end of the bourdon tube.

The gauges were pressurized in 500 psi increments from 500 to 5000 psig per the reference gauge (instrument 4). After the system was pressurized, valves 1 and 2 (see schematic) were closed, then valve 3 was opened and the amount of compressed-trapped oil was exhausted into the graduate (instrument 7) over a total of several runs. The total value of the runs was then divided by the number of runs and an average compressed volume was obtained.

The values of compressed volume were used to determine the "hydraulic capacitance" in Section 1.2.1.3.

1.2.1.2 Gauge Hydraulic Capacitance Test Apparatus

Test Gauges 0-5000 psig (Bourdon Tube)

1. large gauge (8" face)
   Heise no: H 16330

2. medium gauge (6" face)
   Ashcroft no: AMC 4297

3. small gauge (4" face)
   Ashcroft - Duragauge

Reference Gauge (Bourdon Tube)

4. Robertshaw Acragauge
   with SAE 4130 tube
   MSOE no: 9453

Pressure is traceable to N.B.S. on an Ashcroft type 1327. Dual Range Dead Weight Tester serial no. 65-496. Certificate of Accuracy no. IH A65-496 from Manning, Maxwell, and Moore, Inc.; Strattford, Connecticut.

Pressure Transducers

5. Wiancko Engineering Company
   type 3PG 10000
   serial no: 1149

6. Pace Engineering Company
   differential pressure
   with 5000 psid plate installed
   Model no: P3D
   serial no: 15988

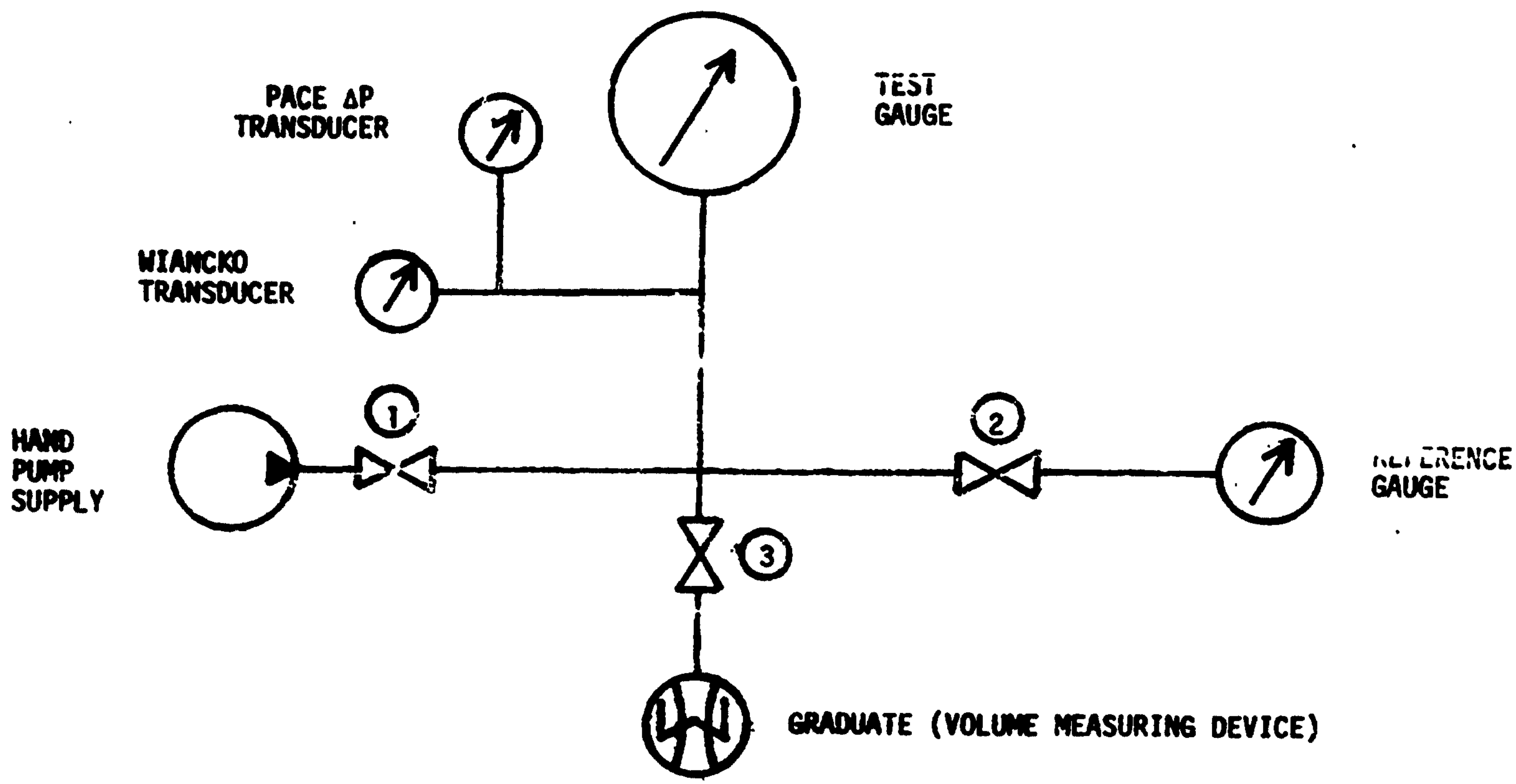
Volume of Capacitance

7. Pyrex Graduate
   0-10 ml 0.1 increments
   no: 3076

Pressure Supply

8. W.S. Pine, Incorporated Hand Pump
   dual piston
   cat. no: 1000A-3-8

FIGURE 1.2.1.2.1 FPI SCHEMATIC FOR HYDRAULIC GAUGE CAPACITANCE INVESTIGATION



Data Table 1.2.1.2.1

Test: Détermination of the Hydraulic Capacitance of a Pressure Gauge

Component: 0-5000 psig Ashcroft Duragage with 4 inch face

Instrumentation: Pyrex #3076 graduate Robertshaw Acragage

Date: December 12, 1975

Technician: R.N.W.

Comment: Data under successive runs represent total accumulated volume

Ref. Pressure psig	Run 1 ml.	Run 2 ml.	Run 3 ml.	Run 4 ml.	Run 5 ml.	Run 6 ml.	Average ml.
500	1.2	2.3	3.5	4.7	5.8	7.1	1.18
1000	1.4	2.65	3.9	5.1	6.4	7.6	1.27
1500	1.3	2.7	3.9	5.2	6.5	7.8	1.3
2000	1.4	2.9	4.2	5.6	6.9	8.2	1.367
2500	1.5	2.9	4.3	5.7	7.1	8.5	1.414
3000	1.5	3.0	4.4	5.9	7.4	8.8	1.467
3500	1.6	3.2	4.7	6.2	7.7	9.2	1.533
4000	1.7	3.3	4.8	6.4	7.9	9.4	1.567
4500	1.8	3.6	5.1	6.6	8.1	9.6	1.6
5000	1.8	3.6	5.2	6.7	8.3	9.9	1.65

Data Table 1.2.1.2.2

Test: Determination of the Hydraulic Capacitance of a Pressure Gauge

Component: 0-5000 psig Ashcroft No.: AMC 4297 with 6 inch face

Instrumentation: Pyrex #3076 graduate Robertshaw Averagage

Date: December 12, 1975

Technician: R.N.W.

Comment: Data under successive runs represent total accumulated volume

Ref. Pressure psig	Run 1 ml.	Run 2 ml.	Run 3 ml.	Run 4 ml.	Average ml.
500	2.0	4.0	6.1	8.2	2.05
1000	2.2	4.4	6.5	8.7	2.175
1500	2.3	4.5	6.8	9.0	2.25
2000	2.4	4.7	7.0	9.3	2.325
2500	2.5	4.9	7.3	9.7	2.425
3000	2.6	5.0	7.5	10.0	2.5
3500	2.7	5.2	7.8	10.3	2.575
4000	2.7	5.4	8.0	10.6	2.65
4500	2.8	5.5	8.2	10.9	2.725
5000	2.9	5.7	8.4	12.2	3.05

Data Table 1.2...2.3

Test: Determination of the Hydraulic of a Pressure Gauge

Component: 0-5000 psig Heise No.: H 16330 with an 8 inch face

Instrumentation: Pyrex #3076 graduate Robertshaw Acragage

Date: December 12, 1975

Technician: R.N.W.

Comment: Data under successive runs represent total accumulated volume

Ref. Pressure psid	Run 1 ml.	Run 2 ml.	Run 3 ml.	Run 4 ml.	Average ml.
500	1.3	2.4	3.5	4.8	1.2
1000	1.4	2.7	3.9	5.2	1.3
1500	1.5	2.8	4.1	5.5	1.375
2000	1.5	2.9	4.3	5.7	1.425
2500	1.5	3.0	4.5	5.9	1.475
3000	1.6	3.2	4.7	6.2	1.55
3500	1.7	3.3	4.8	6.5	1.625
4000	1.7	3.3	4.9	6.6	1.65
4500	1.8	3.4	5.0	6.8	1.7
5000	1.8	3.5	5.2	7.0	1.75

1.2.1.3 Simulation of Snubber Gauge Pressure Measuring System

Purpose: To determine the amount error caused by the non-symmetrical characteristic of the snubbing orifice using:

a) a laboratory derived model of the snubbing orifice;
b) a laboratory derived model of the pressure measuring gauge; and
c) a digital computer program simulation of the pressure source and the overall system.

1.2.1.3.1 Snubber Equation Derivation

Using the laboratory data obtained in Section 1.2.1.1, characteristic equations for various degrees of snubbing (i.e., 20°, 25°, and 10°), were obtained.

The P-Q characteristic, in general, for the orifice can be shown to be the following:

$$P = KQ^n$$

where: P is the pressure drop across the orifice in psi,
Q is the flow through the orifice in gpm,
K and n are the characteristics of the orifice.

If the $\log_{10}$ is taken for both sides of the above equation, this results in:

$$\log_{10}P = n \log_{10}Q + \log_{10}K \ .$$

The above equation closely resembles the equation of a straight line:

$$y = mx + b$$

where: $y = \log_{10}P$
$m = n$
$x = \log_{10}Q$
and $b = \log_{10}K$.

A simple least-squares curvefit can now be employed to determine n and $\log_{10}$ K. Actual calculations for these values were performed using HP-55 programmable calculator and the program given below.

01	R/S	05	f
02	f	06	$\log_{10}$
03	$\log_{10}$	07	Σ
04	R/S	08	GOTO-01

After all values of P and Q have been entered, the linear regression function of the calculator was used to give $\log_{10} K$ and n. From this point, it is a simple operation to take the anti-log to obtain K. The table below represents a summary of various applications of the program.

TABLE 1.2.1.3.1

Summary of Snubber Characteristics

Degree of Snubbing	Forward K	Forward n	Reverse K	Reverse n
10°	38945.3	1.05	39465.6	1.01
20°	5481.5	1.05	5001	1.07
25°	3100.6	1.06	3095.3	1.05
30°	2307.95	1.03	1810.8	0.99

1.2.1.3.2 Hydraulic Gauge Capacitance Equation

It can be shown that the pressure-volume relationship for the bourdon tube pressure gauge is:

$$P = -14.7 + \frac{K}{V_o - V}$$

where: P is the pressure in psi,
V is the volume in gal.,
V_o is the total volume in gal.,
and K is a characteristic of the gauge.

The hydraulic capacitance is defined as the rate of change of volume with respect to pressure. That is,

$$C = \frac{dV}{dP}\ .$$

Applying the derivative to the original equation gives

$$C = \frac{K}{(P+14.7)^2}\ .$$

A suitable value of K can be derived using a least-squares curve fit using the laboratory data obtained in section 1.2.1.2 and the equation:

$$P = -14.7 + \frac{K}{V_o - V}$$

Rearrangement of the above equation results in:

$$(P + 14.7)V_o + (-K) = (P + 14.7)V$$

which resembles the equation of a straight line

$$y = mx + b$$

where $y = (P + 14.7)(V)$
$x = P + 14.7$
$m = V_o$
$b = -K$.

The calculations necessary to obtain the least-square's fit were again performed on a programmable HP-55 calculator using the program below:

01	R/S	11	CHS
02	1	12	-3
03	4	13	x
04	.	14	f
05	7	15	ℓ to gal(conversion)
06	+	16	x
07	STO	17	RCL
08	1	18	1
09	R/S	19	Σ
10	EEX	20	GO TO-01

1.2.1.3.3 Computer Program

The simulation of the snubber orifice and hydraulic gauge capacitance was primarily based on the data obtained from the preceeding two sections and the simulation equation which was derived as follows:

The schematic representation of the system under study is given below:

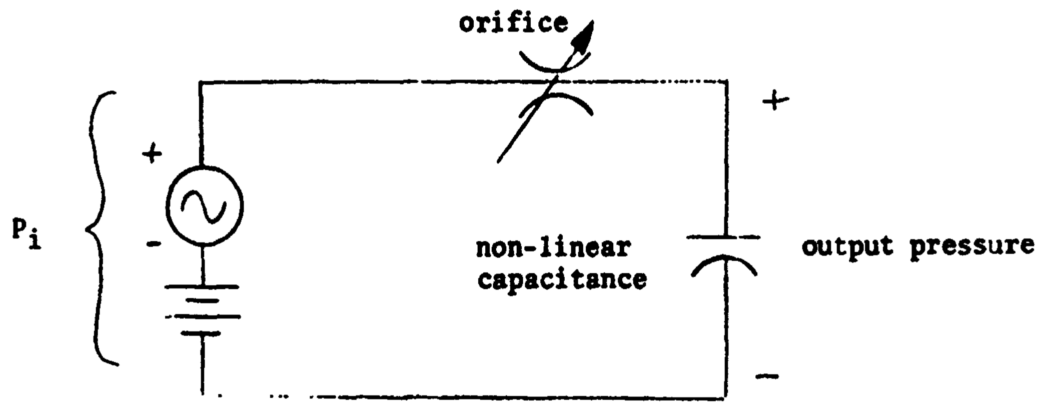


FIGURE 1.2.1.3.3.1

A typical input pressure based on a fourier analysis of the output pressure of a pump* is given by:

$$Pi = 3000 + 234.4 \cos(2356.2t + 2.304) + 71.3 \cos(4712.4t + 2.89)$$

$$+ 3.8 \cos(7068t - 29.49) + 1.7 \cos(4712.4t + 1.27) + 7.5\cos(11780.9t + 1.5)$$

where all angles are measured in radians and the fundamental frequency of oscillation is 375 H_Z. This frequency of oscillation is based on a typical nine piston pump operating at a speed of 2500 RPM.

$$f_{osc} = \frac{9 \times 2500 \text{ rev/min}}{60 \text{ sec/min}} = 375 \text{ } H_Z \text{ .}$$

The equations describing the flow through the orifice and capacitance are respectively:

$$q_o = \sqrt[n]{\frac{P_o}{K_1}} = \sqrt[n]{\frac{P-Pi}{K_1}}$$

$$q_C = C \frac{dP}{dt} = \frac{K_2}{(P+14.7)^2} \frac{dP}{dt}$$

* Unruh, D. R. "Outlet Pressure Ripple Measurement of Positive Displacement Pumps," National Fluid Power Conference, 1975, page 728.

where: P_o is the pressure drop across the orifice,
K_1, K_2, and n are constants previously developed,
and P_i is the output pressure.

Since the orifice and the capacitance are connected in series,

$$q_C = -q_o$$

and,

$$\frac{K_2}{(P+14.7)^2} \quad \frac{dP}{dt} = - \sqrt[n]{\frac{-Pi}{K_1}}$$

Solving for the slope gives:

$$\frac{dP}{dt} = - \frac{(P + 14.7)^2}{K_2} \cdot \sqrt[n]{\frac{P-I\ I}{K_1}}$$

which is the basis for the following simulation program.

Two programs appear on the following pages. Program T, is the basic simulation program which provides numerical output, and program TP provides a plot of the response. These programs were run on an Interdata Model 14 minicomputer using a slightly modified version of Fortran.

The program requests input data of the following form:

a) the word DATA or PLOT depending on the type of output desired
b) the forward and reverse characteristics of the snubber orifice along with the appropriate exponents;
c) output interval and finish period.

And, if a plot is requested

d) plotting output interval;
e) scaling values for input/output pressures in the form of maximum and minimum pressure excursions.

Output for the program is given by

a) an interval counter (based on the Δt intervals);
b) elapsed time in seconds;
c) input pressure and its average;
d) output pressure and its average.

After all values of P and V have been entered, the linear regression function of the calculator was used to obtain V_o and K. The table below represents a summary of typical gauge values.

TABLE 1.2.3.2.1

Summary of Gauge Capacitance Calculations

(all gauges 5000 psi)

Gauge	K	V_o (gal)
1. Duragage 4" face	.1432149	4.5119×10^{-4}
2. Ashcroft 5.5" face	.33470784	6.9936×10^{-4}
3. Heise 8" face	.1649556	4.8065×10^{-4}

COMPUTER PROGRAM

```
      SUPR T
      DIMF PA(50),PV(50)
      ACCF PK
      ACCF K2,K3,K4,K5
      ACCF 0U,TF
      CT=0
      K=0
      TP=1/375
      K2=K2*60**K3
      K4=K4*60**K5
      DT=TP/20
      TF=TF*TP
      P=3000
      T=-DT
      I=0
      IC=0
10    C0NT
      A0=0
      AI=0
      T=T+DT
      IC=IC+1
      CT=CT+1
      PI=3000+234.4*C0S(2356.2*T+2.304)
      PI=PI+71.3*C0S(4712.4*T+2.89)
      PI=PI+8.8*C0S(7068*T-29.49)+1.7*C0S(9427.8*T+1.27)
      PI=PI+7.5*C0S(11780.9*T+1.5)
      CP=.143215/(P+14.7)**2
      IF (P-PI) 91,91,92
91    DP=-(1/CP)*((P-PI)/K2)**(1/K3)
      G0 90
92    DP=-(1/CP)*((P-PI)/K4)**(1/K5)
90    C0NT
      P=P+DP*DT
      IF (PK-"PL0T") 27,15,27
27    I=I+1
      PA(I)=P
      PV(I)=PI
      IF (I-TP/DT) 15,20,20
20    D0 40 J=1,I
      AI=AI+PV(J)
40    A0=A0+PA(J)
      A0=A0/I
      AI=AI/I
      D0 37 J=2,I
      PA(J-1)=PA(J)
37    PN(J-1)=PN(J)
      I=I-1
15    IF (IC-0U) 10,46,46
46    IC=0
      IF (PK-"PL0T") 87,86,87
86    CALL TP
      G0 32
87    TYPE '(1X,I3,2X,F9.3,4F11.3)',CT,T,PI,AI,P,A0
32    K=1
      IF (T-TF) 10,10,21
21    C0NT
      END
```

```
     SUBR TP
     IF (K) 44,45,44
45   CØNT
     IX=0
     P1="*    "
     P2="+    "
     ACCE IN
     ACCE M1,N1,M2,N2
44   CØNT
     IF (IX-IN) 4,11,11
11   IX=0
     X1=((PI-N1)/(M1-N1))*49+1
     X2=((P-N2)/(M2-N2))*49+1
6    TYPE '(1X,I4,SA1,SA1)',CT,X1,P1,X2,P2
4    IX=IX+1
     END
```

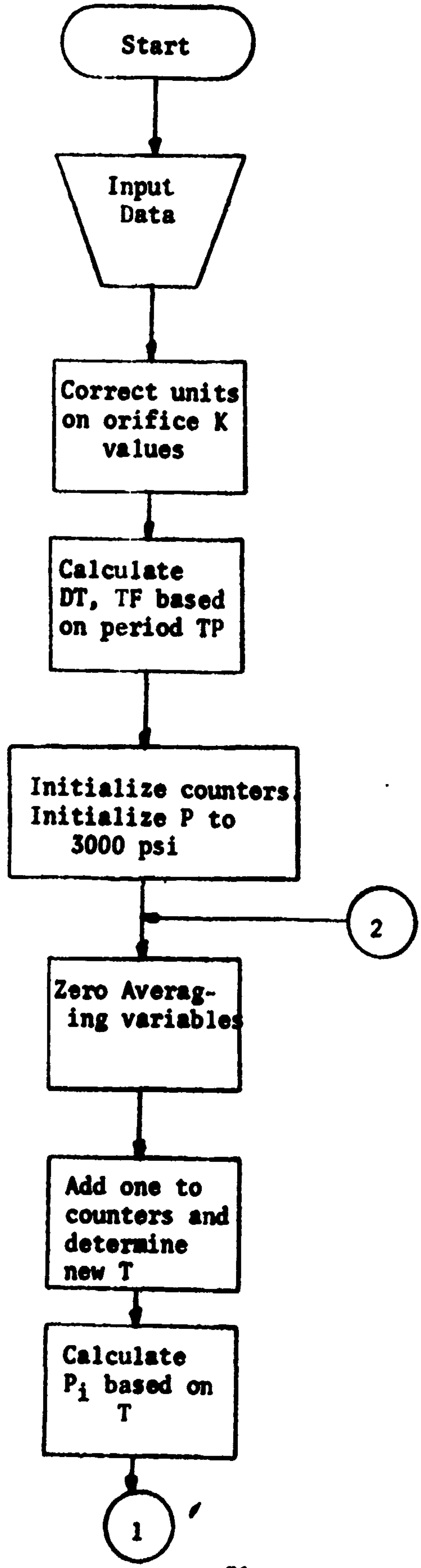
A summary of the variables used in the program appears below:

Variables	Function
CT, I, IC, J, K, IX	Counters
OU	Output interval
P	Output pressure in psi
PI	Input pressure in psi
K2	Forward orifice constant
K3	Forward orifice exponent (n)
K4	Reverse orifice constant
K5	Reverse orifice exponent (n)

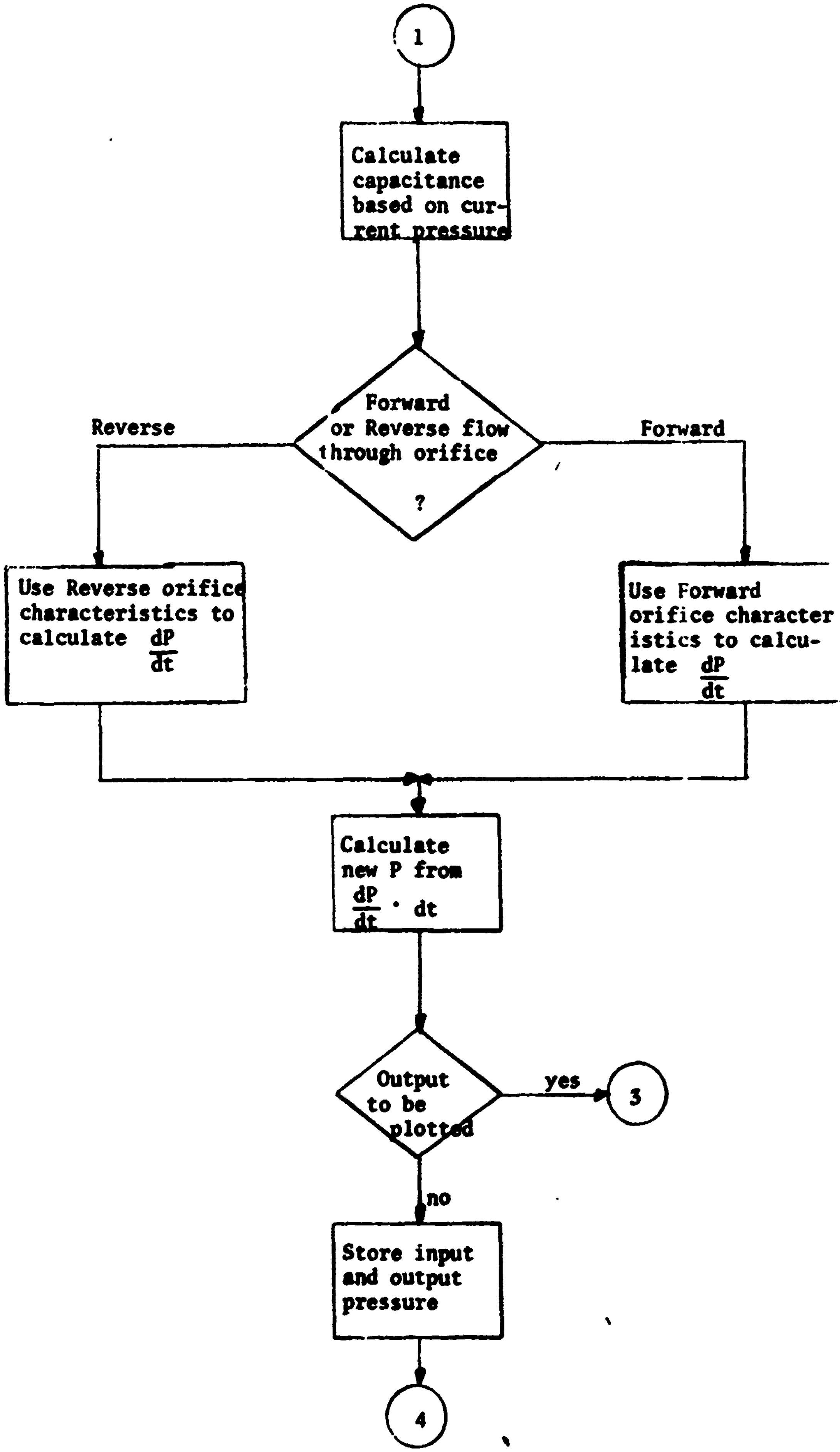
Note: K2 and K4 are modified to provide consistant units of seconds.

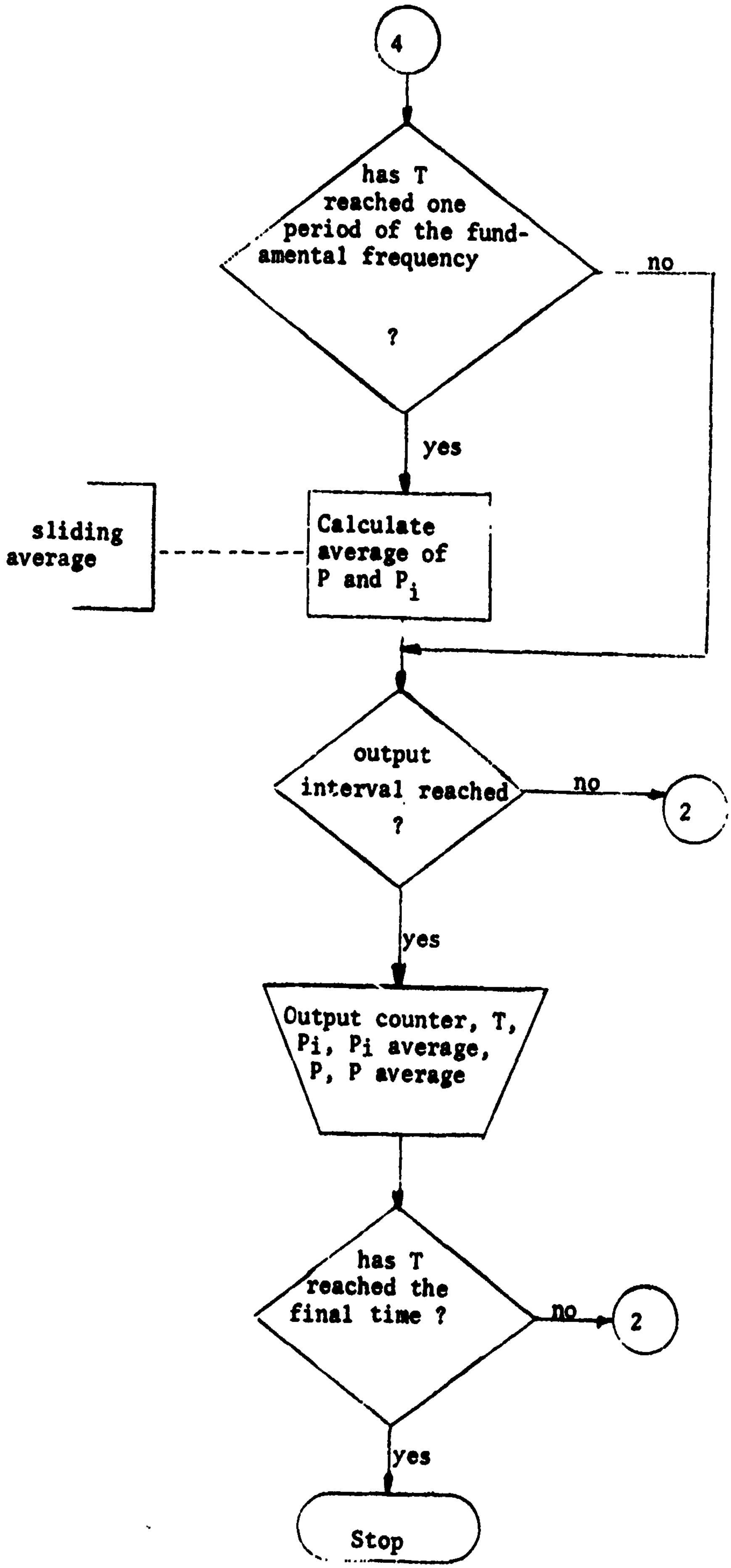
T	Elapsed simulation time in seconds
DT	Calculation interval
TF	Finish time in seconds
TP	Fundamental period of input waveform in seconds
CP	Non-linear capacitance value
DP	dP/dt, the slope of the P curve
PA, PN	Storage arrays for averages
AO, AI	Average values of output and input waveforms respectively
PK	Determines if DATA or PLOT is to be outputted
P1, P2	Input/Output pressure plotting characters for graphing routine
X1, X2	Input/Output pressure sealing variables

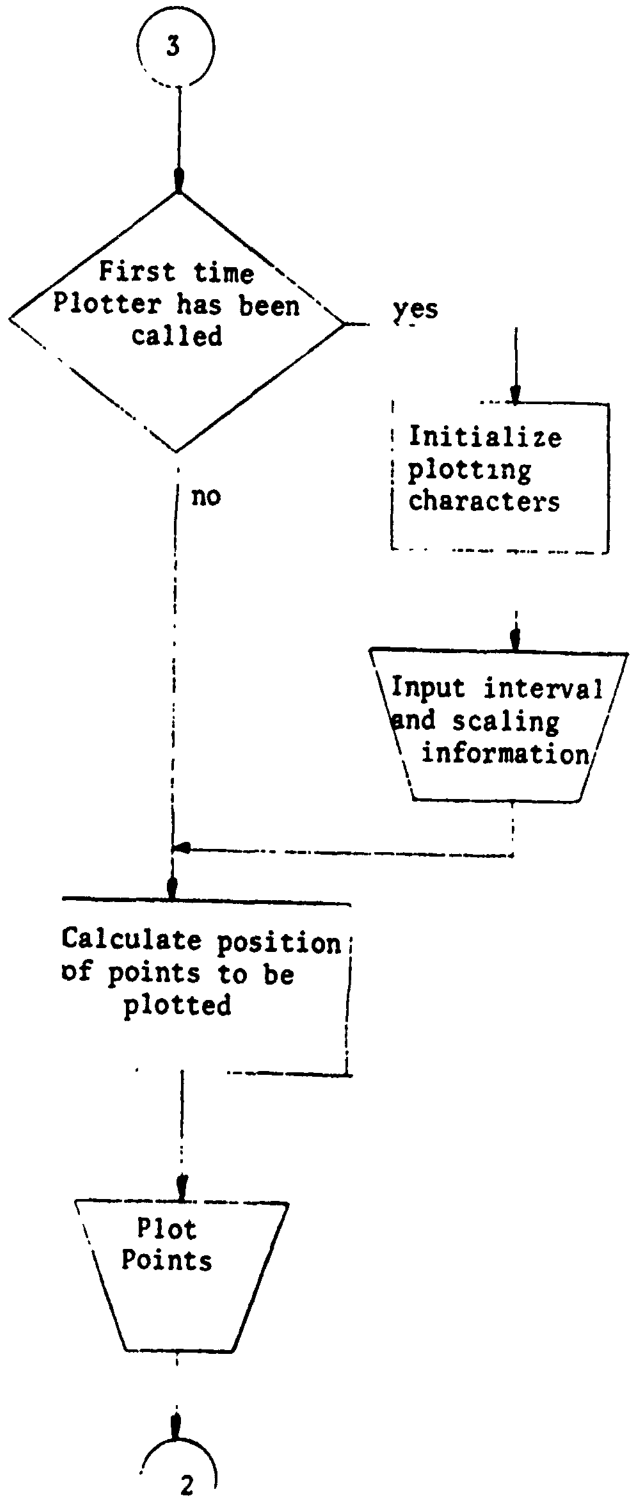
A simplified flowchart for the program is shown on the following pages. The technique employed is based on a straight forward Euler numerical integration process.



Start
Input Data
Correct units on orifice K values
Calculate DT, TF based on period TP
Initialize counters Initialize P to 3000 psi
2
Zero Averaging variables
Add one to counters and determine new T
Calculate P_i based on T
1


1
Calculate capacitance based on current pressure
Forward or Reverse flow through orifice ?
Reverse
Forward
Use Reverse orifice characteristics to calculate dP/dt
Use Forward orifice characteristics to calculate dP/dt
Calculate new P from dP/dt · dt
Output to be plotted
yes
3
no
Store input and output pressure
4


4
has T reached one period of the fund-amental frequency ?
no
yes
sliding average
Calculate average of P and Pi
output interval reached ?
no
2
yes
Output counter, T, Pi, Pi average, P, P average
has T reached the final time ?
no
2
yes
Stop


3
First time Plotter has been called
yes
no
Initialize plotting characters
Input interval and scaling information
Calculate position of points to be plotted
Plot Points
2

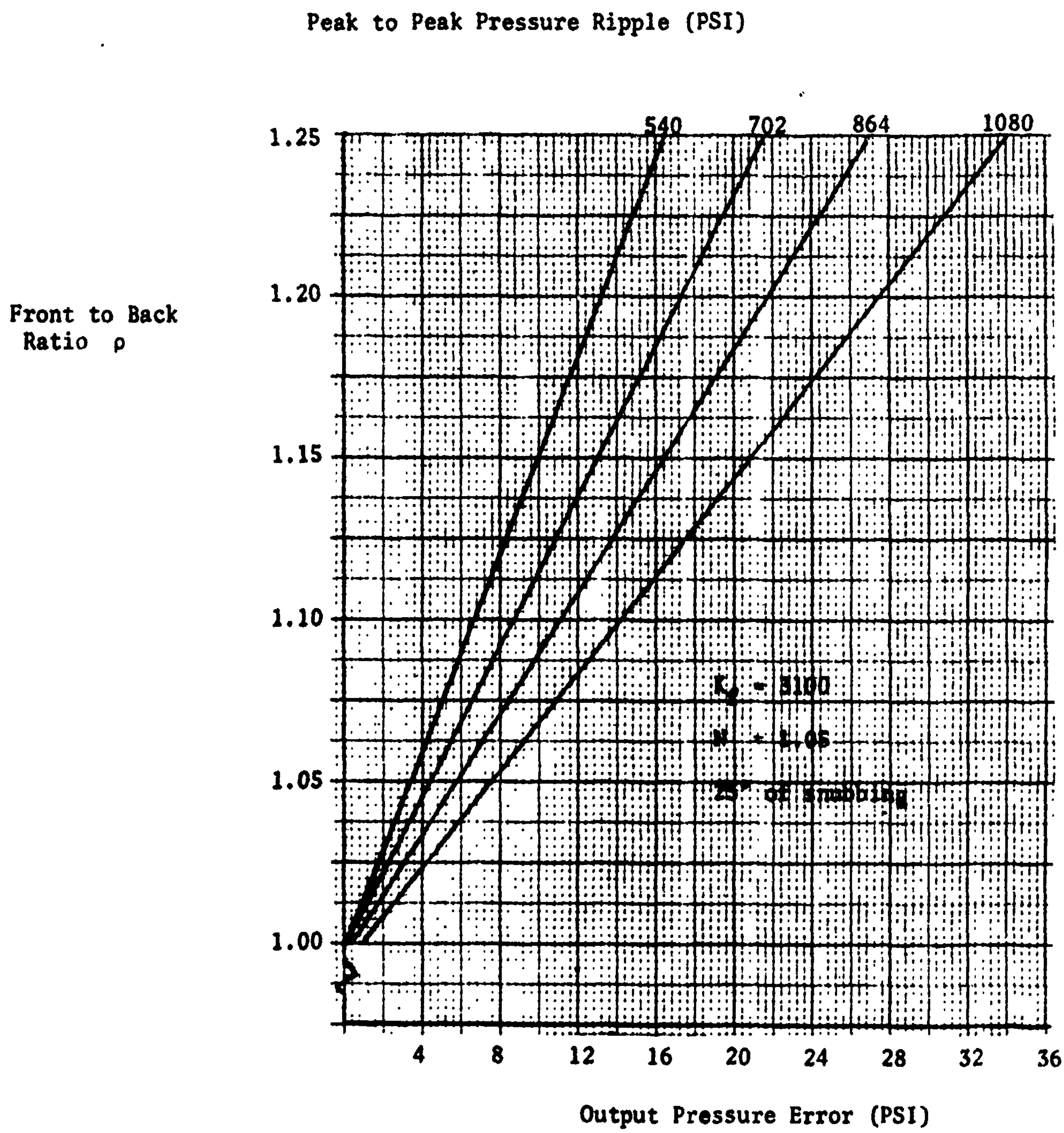


Figure 1.2.1.3.3.2

Front to Back Ratio (ρ) as a function of Output Pressure Error and Peak to Peak Pressure Ripple

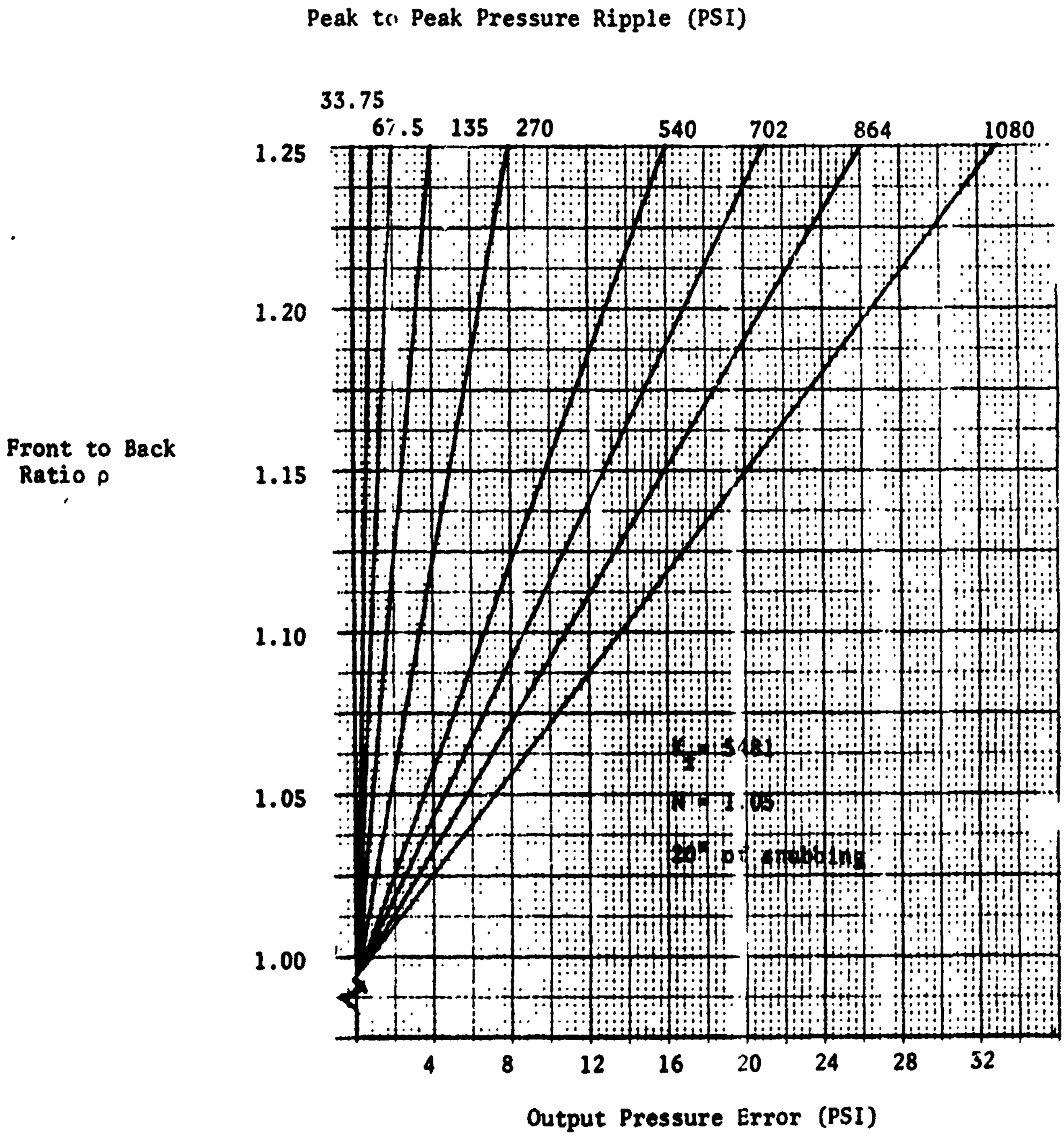


Figure 1.2.1.3.3.3

Front to Back Ratio (ρ) as a function of Output Pressure Error and Peak to Peak Pressure Ripple

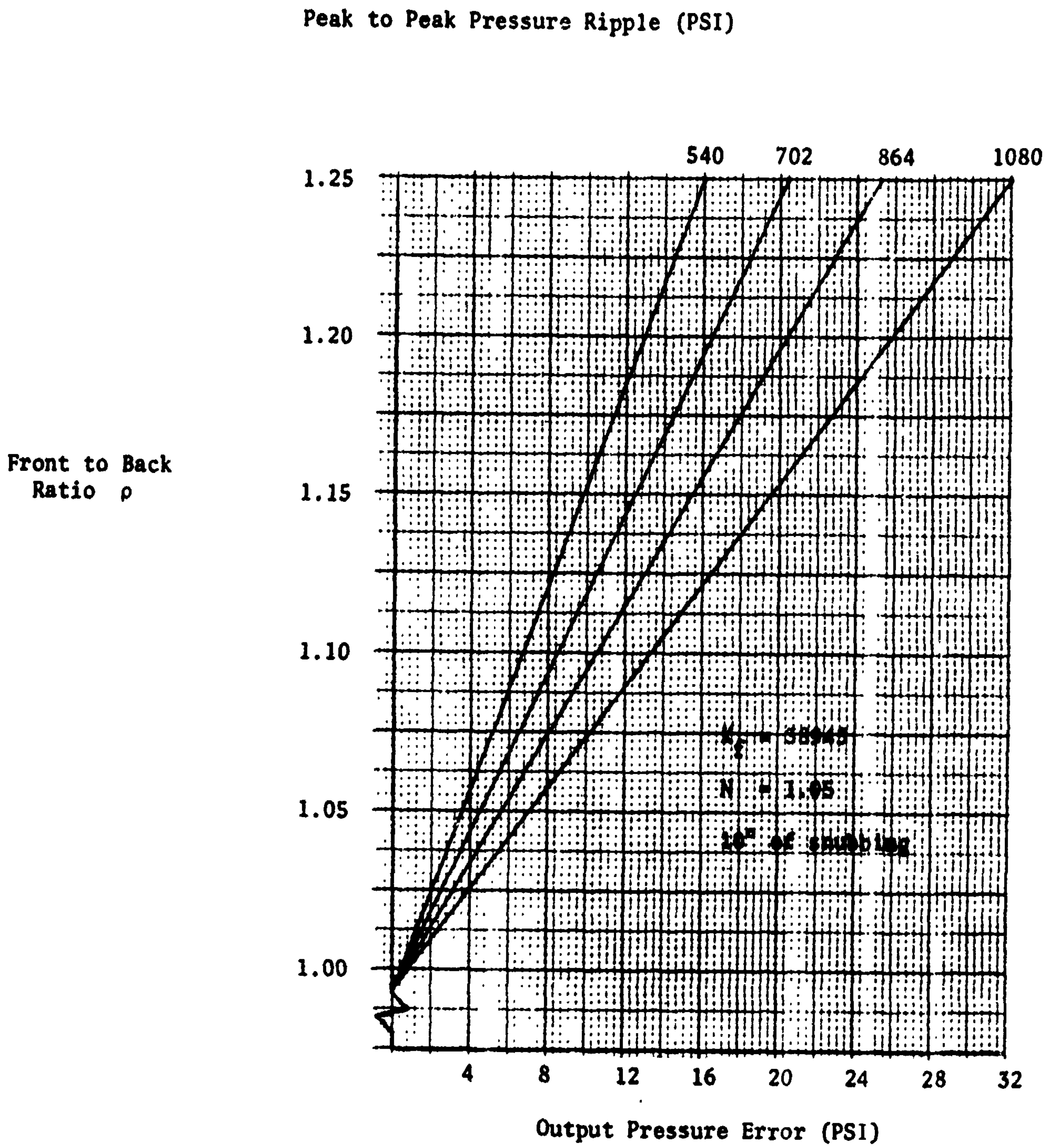


Figure 1.2.1.3.3.4

Front to Back Ratio (ρ) as a function of Output Pressure Error and Peak to Peak Pressure Ripple

Numerous runs were made varying the front to back ratios of the K value of the orifice, and the peak to peak pressure ripple. Each time, the steady state average value of the output pressure ripple was recorded. The reverse characteristic was taken as 100%, 95%, 90%, 85%, and 80% of the forward characteristic. These values represented ρ values (front to back ratio) of 1.00, 1.053, 1.111, 1.176, and 1.250 respectively. Three different degrees of snubbing were used and they represented 10°, 20°, and 25°.

In addition the effect of increasing the peak to peak pressure ripple and the DC value of the input pressure was investigated. The summary of these computer runs maybe found in the graphs of Figures 1.2.1.3.3.2, 3, and 4.

TABLE 1.2.1.3.3.1

Computer Output Summary

DC Input Pressure = 3000(psi)

DEGREE OF SNUBBER SETTING	K_F VALUE (FORWARD) N = 1.05	PEAK TO PEAK PRESSURE RIPPLE	K_r AS A PERCENT OF K_F	FRONT TO BACK RATIO (ρ)	AVERAGE STEADY STATE OUTPUT PRESSURE (psi)
10	38945	540	100	1.000	3000.21
			95	1.053	2996.53
			90	1.111	2992.63
			85	1.176	2988.48
			80	1.250	2984.08
		702	100	1.000	3000.26
			95	1.053	2995.47
			90	1.111	2990.40
			85	1.176	2985.01
			80	1.250	2979.28
		864	100	1.000	3000.29
			95	1.053	2994.40
			90	1.111	2988.16
			85	1.176	2981.53
			80	1.250	2974.48
		1080	100	1.000	3000.33
			95	1.053	2992.97
			90	1.111	2985.16
			85	1.176	2976.88
			80	1.250	2968.07
20	5481	540	100	1.000	3000.17
			95	1.053	2996.41
			90	1.111	2992.42
			85	1.176	2988.20
			80	1.250	2983.71
		702	100	1.000	3000.09
			95	1.053	2995.20
			90	1.111	2990.02
			85	1.176	2984.53
			80	1.250	2978.69
		864	100	1.000	2999.96
			95	1.053	2993.94
			90	1.111	2987.56
			85	1.176	2980.80
			80	1.250	2973.61
		1080	100	1.000	2999.70
			95	1.053	2992.18
			90	1.111	2984.2
			85	1.176	2975.74
			80	1.250	2966.76

TABLE 1.2.1.3.3.1 (cont)

DEGREE OF SNUBBER SETTING	K_F VALUE (FORWARD) N = 1.05	PEAK TO PEAK PRESSURE RIPPLE	K_r AS A PERCENT OF K_F	FRONT TO BACK RATIO (ρ)	AVERAGE STEADY STATE OUTPUT PRESSURE (psi)
20	5481	270	100	1.000	3000.17
			95	1.053	2998.29
			90	1.111	2996.29
			85	1.176	2994.18
			80	1.250	2991.94
		135	100	1.000	3000.11
			95	1.053	2999.17
			90	1.111	2998.17
			85	1.176	2997.11
			80	1.250	2995.99
		67.5	100	1.000	3000.06
			95	1.053	2999.59
			90	1.111	2999.09
			85	1.176	2998.56
			80	1.250	2998.00
		33.75	100	1.000	3000.04
			95	1.053	2999.80
			90	1.111	2999.55
			85	1.176	2999.28
			80	1.250	2999.01
25	3100	540	100	1.000	3000.03
			95	1.053	2996.25
			90	1.111	2992.26
			85	1.176	2988.05
			80	1.250	2983.56
		702	100	1.000	2999.81
			95	1.053	2994.91
			90	1.111	2989.71
			85	1.176	2984.23
			80	1.250	2978.39
		864	100	1.000	2999.51
			95	1.053	2993.46
			90	1.111	2987.06
			85	1.176	2980.30
			80	1.250	2973.12
		1080	100	1.000	2998.95
			95	1.053	2991.38
			90	1.111	2983.37
			85	1.176	2974.91
			80	1.250	2965.93

TABLE 1.2.1.3.3.2

Steady State Output Error as a Function of DC Input Pressure

$K_F = 5481$

Peak to Peak Pressure Ripple = 540 psi

K_T AS A PERCENT OF K_F	INPUT DC (psi) PRESSURE	ERROR IN AVE. STEADY-STATE OUTPUT (psi)
100%	3000	0.2
	2000	0.1
	1500	0.1
95%	3000	3.6
	2000	3.6
	1500	3.6
90%	3000	7.6
	2000	7.5
	1500	7.5
85%	3000	11.8
	2000	11.7
	1500	11.5
80%	3000	16.3
	2000	16.1
	1500	15.9

1.2.1.3.4 Summary and Conclusions

The following conclusions, with regard to the parameters affecting the error in the average steady state output pressure, are evident from the preceeding analysis.

1. Front to Back Ratio of the Snubber Conductivity Coefficients

The error in the average steady state output pressure is a function of the front to back ratio of the conductivity coefficients of the snubber orifice. Increased ratios provide a non-linear increase in error. If the orifice is symmetrical (i.e., front to back ratio is 1.000), the error in the average output pressure is a minimum.

2. Relative Magnitude of the Conductivity Coefficients

Increased values of K, resulting from a tighter snubber setting, slightly lower the error in steady state average output pressure. The difference in K resulting from a change in snubber setting of 3100 to 38945 changed the error in average output pressure by only 3%.

3. Relative Direction of the Error Indication

The average steady state output pressure will read lower if the forward K characteristic of the snubber orifice is greater than the reverse. If the reverse characteristic has the greater K, the average output pressure will read higher.

4. Average Pressure of the Source

The average level of the input pressure does not effect the error in average steady state output pressure as evident from Table 1.2.1.3.3.2.

5. Peak to Peak Pressure Ripple

The average steady state output pressure error increases with an increase in the peak to peak pressure ripple. Double the peak to peak pressure ripple approximately doubles the relative magnitude of the error in the pressure reading.

6. Input Waveshape

The input waveform for any pump maybe represented by a series of sinusoidal waveforms whose relative magnitudes and fundamental frequency may be determined by fourier analysis. Because each term in the series is sinusoidal and symmetrical about the average pressure level, the error contribution is a function of the peak to peak ripple and not the shape of the composite waveform.

7. Exponent in the P-Q Characteristic

The relative magnitude of the exponent in the P-Q characteristic exhibits a relatively minor change as the degree of snubbing is varied. This is shown in Table 1.2.1.3.1. The exponent varied only 3% over the range of settings investigated.

8. Actual Errors Measured

A table summarizing the error in average output pressure as a function of the front to back ratio and the peak to peak pressure ripple, expressed as a percentage is given below.

TABLE 1.2.1.3.4.1

Errors in Output Pressure Reading

FRONT TO BACK RATIO (ρ)	ERROR AS A PERCENTAGE OF THE PEAK TO PEAK PRESSURE RIPPLE FOR P-P VALUE OF 540 psi	FOR P-P VALUE OF 1080 psi
1.000	0.0	0.0
1.053	0.7	0.7
1.111	1.4	1.5
1.176	2.2	2.3
1.250	3.0	3.1

From the preceeding discussion, it is apparent that the error in average steady state output may be predicted from a knowledge of the front to back ratio and the peak to peak pressure ripple in the input pressure.

Table 1.2.1.3.4.2 shows the allowable range of front to back ratios for various error contributions of 0.1%, 0.5%, and 1.0%. The values in the table were determined from the following:

1. Determine the desired accuracy of measurement (0.1%, 0.5% or 1.0%)

2. Determine allowable ΔP error for a given average input pressure.

3. Determine a peak to peak pressure ripple.

4. With the aid of Figure 1.2.1.3.3.3, determine the maximum allowable front to back ratio (ρ).

With the aid of Table 1.2.1.3.4.2, Figure 1.2.1.3.4.1 maybe drawn. Each curve represents the three error contributions of 0.1%, 0.5%, and 1.0% respectively.

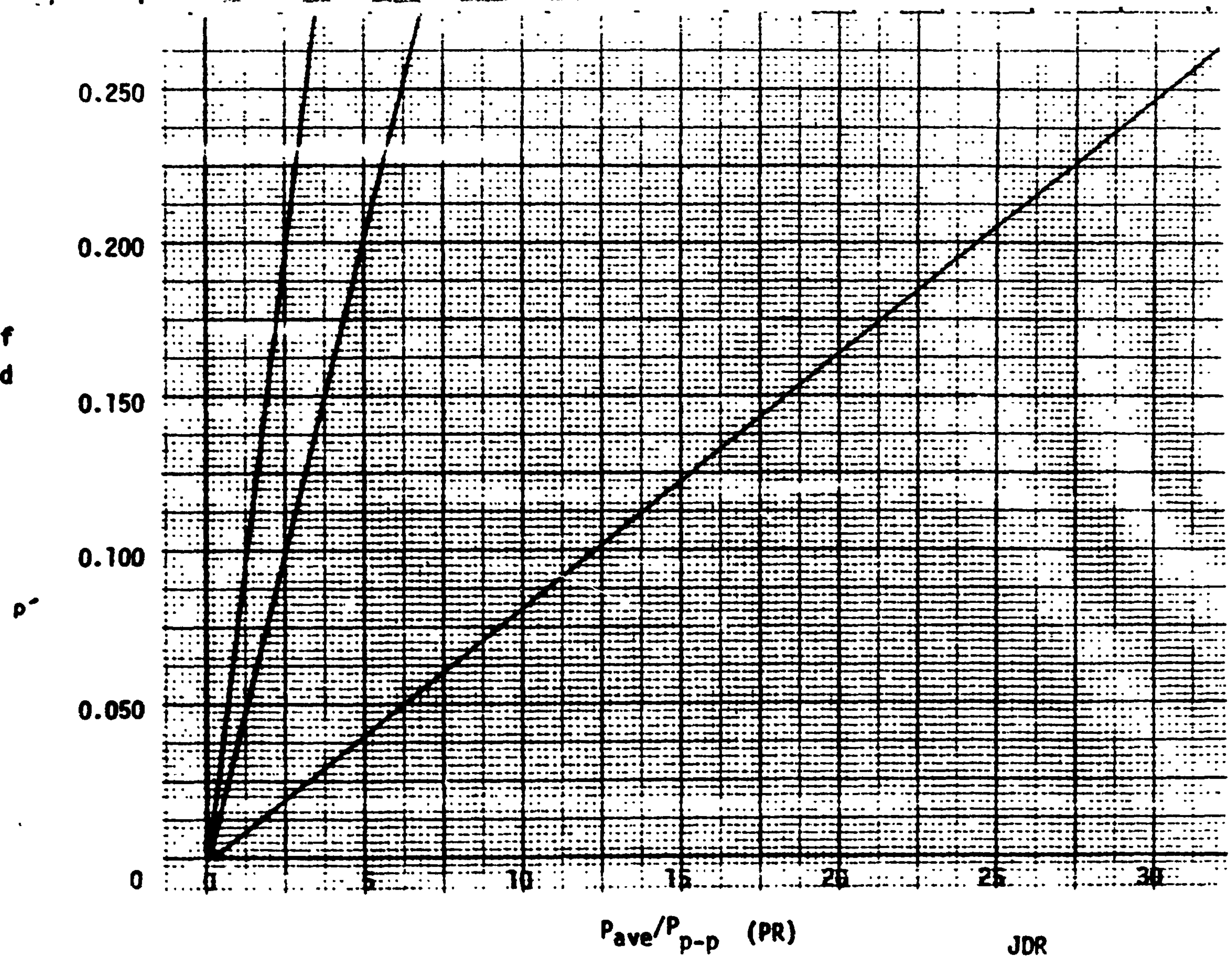
Table 1.2.1.3.4.2

Maximum ρ Value for 0.1%, 0.5%, and 1% Error Contributions

Peak to Peak (PSI)	$P_{ave.}$	$\frac{P_{ave.}}{P\text{-}P}$	0.5% EC ΔP	0.5% EC $\rho_{max.}$	0.1% EC ΔP	0.1% EC $\rho_{max.}$	1.0% EC ΔP	1.0% EC $\rho_{max.}$
33.75	500	14.810	2.5		.5	1.125		
67.50	500	7.410	2.5		.5	1.058	5	
135.00	500	3.700	2.5	1.154	.5	1.032	5	
270.00	500	1.852	2.5	1.075	.5	1.014	5	1.149
540.00	500	0.923	2.5	1.035	.5	1.007	5	1.072
702.00	500	0.712	2.5	1.026	.5	1.005	5	1.054
864.00	500	0.579	2.5	1.021	.5	1.004	5	1.043
1080.00	500	0.463	2.5	1.016	.5	1.003	5	1.032
33.75	1000	29.630	5		1	1.250	10	
67.50	1000	14.810	5		1	1.119	10	
135.00	1000	7.410	5		1	1.061	10	
270.00	1000	3.700	5	1.150	1	1.029	10	
540.00	1000	1.852	5	1.072	1	1.013	10	1.148
702.00	1000	1.425	5	1.055	1	1.010	10	1.111
864.00	1000	1.157	5	1.042	1	1.009	10	1.089
1080.00	1000	0.926	5	1.030	1	1.006	10	1.068
33.75	1500	44.444	7.5		1.5		15	
67.50	1500	22.222	7.5		1.5	1.181	15	
135.00	1500	11.111	7.5		1.5	1.092	15	
270.00	1500	5.556	7.5	1.225	1.5	1.045	15	
540.00	1500	2.778	7.5	1.108	1.5	1.021	15	1.229
702.00	1500	2.137	7.5	1.082	1.5	1.015	15	1.170
864.00	1500	1.736	7.5	1.066	1.5	1.013	15	1.135
1080.00	1500	1.384	7.5	1.051	1.5	1.009	15	1.104
33.75	2000	59.260	10		2		20	
67.50	2000	29.630	10		2	1.250	20	
135.00	2000	14.815	10		2	1.123	20	
270.00	2000	7.410	10		2	1.060	20	
540.00	2000	3.852	10	1.147	2	1.028	20	
702.00	2000	2.849	10	1.110	2	1.020	20	1.231
864.00	2000	2.315	10	1.087	2	1.0175	20	1.186
1080.00	2000	1.890	10	1.070	2	1.0125	20	1.1425
33.75	3000	88.889	15		3		30	
67.50	3000	44.444	15		3		30	
135.00	3000	22.222	15		3	1.185	30	
270.00	3000	11.111	15		3	1.089	30	
540.00	3000	5.556	15	1.229	3	1.0425	30	
702.00	3000	4.274	15	1.170	3	1.031	30	
864.00	3000	3.472	15	1.135	3	1.026	30	
1080.00	3000	2.777	15	1.104	3	1.019	30	1.222

Maximum Allowable ρ'

Value as a function of error contribution and the ratio of P_{ave} to P_{p-p} ripple



JDR
13 April, 1976

FIGURE 1.2.1.3.4.1

9. Error Equation Derivation

A least squares fit may be found for each of the curves in Figure 1.2.1.3.4.2 assuming a straight line form.

A new ρ may be defined as follows: which facilitates its usage in a log-log graph:

$$\rho' = \frac{K_f - K_b}{K_b} = \rho_{max} - 1$$

where ρ_{max}, K_f, and K_b were previously defined.

An equation for each of the error contributions may be shown to be of the form:

$$\rho' = m\,(PR) + b$$

where $PR = P_{ave}/P_{P-P}$. The resulting equations are

1% Error Contribution

$$\rho' = .083(PR) - .0071$$

0.5% Error Contribution

$$\rho' = .042(PR) - .0057$$

0.1% Error Contribution

$$\rho' = .0084(PR) - .0024$$

It can be seen from the slope for the three different values of error contribution, that the slope in turn is directly proportional to the error contribution. Performing a least squares fit on m and EC yields:

$$\rho' = 0.08285\ (PR)(EC)$$

The maximum allowable front to back ratio, ρ_{max}, may be predicted by a knowledge of the pressure ratio ($P_{ave}/P\text{-}P$), and the error contribution desired (expressed as a percent) by the equation

$$\rho_{max} = 0.08285\ (PR)(EC) + 1\ .$$

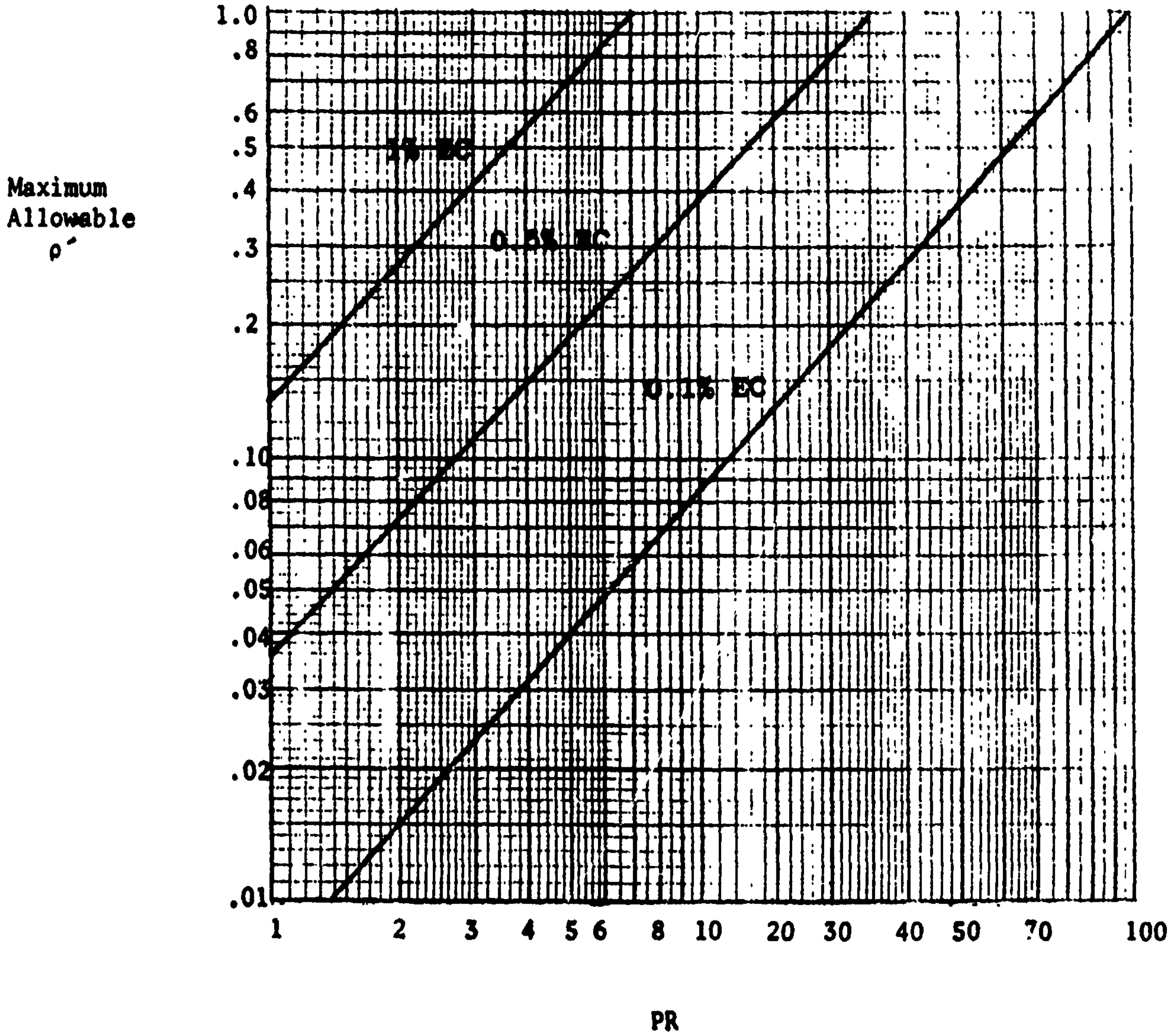


Figure 1.2.1.3.4.2

Maximum allowable ρ' based on the pressure ratio and error contributions as a percent represented by the equation:

$$\rho' = 0.083(EC)(PR) - 1$$

1.3 Laboratory Studies

This effort was directed twoard investigation of the effects that tap hole quality has upon pressure measurement error. Although it emphasizes steady-state, very cursory investigations were made on the effects of burrs on dynamic pressure measurement.

1.3.1 Tap Hole Quality-Steady State

Purpose: To estimate the error in measurement contributed by the burrs created during the machining of the tap-hole, to assess the need for more than one hole in a pres.ure tap and to assess the quality of the tap required for a given accuracy class.

1.3.1.1 Tap Construction Methods

Tap holes were drilled radially into two pipe sizes, 1/2 inch and 1 1/2 inch. To simulate the effects of crude hole construction, a hand drill was used on several tap holes, which left burrs of varying sizes and shapes. In other holes, the machining was conducted with more care and the resultant burrs were carefully removed by one of two methods. In all cases, each series of holes (a series is a set of 6 or 4 tap holes drilled radially about a single circumferential scribe mark at a specified axial location on the pipe) contained at least one carefully deburred hole which was used as a reference to which all other holes would be compared. This section contains the details on machining and deburring each of the two pipe sizes.

1.3.1.1.1 1 1/2 Inch Pipe Size

1.3.1.1.1.1 Drilling Procedure

Eight series of holes, consisting of six holes per series, were drilled in a 50 inch length of 1 1/2 inch nominal size, schedule 80 welded black iron test pipe. Radial locations for these holes were determined using a template (see Figure 1.3.1.1.1.1.2). The template was hand held on the pipe, lines were scribed around all four sides of the template and around the three holes within the template (see Figure 1.3.1.1.1.1.2). The template was next placed on the other side of the pipe and aligned to the previously scribed lines. The necessary scribe marks were then made on that side. The first series of holes, series one, was drilled six inches from the downstream end of the test pipe. Each additional series was drilled four inches upstream from the previously drilled series. Selection of tap locations was based upon current work in ISO/TC-131/SC-8.

In series one through five, the test holes were center punched and drilled, using a 5/32 inch standard straight shank twist drill bit and an electric hand drill (see Figure 1.3.1.1.1.1.2).

In series six and seven, six different size holes were drilled. The hole sizes were 3/32 inch, 5/32 inch, 1/4 inch, 21/64 inch, 13/32 inch, and 1/2 inch.

To prevent overlapping of the larger hole sizes, it was necessary to relocate the center points of the larger holes. This was accomplished by moving the larger hole center approximately 1/8 of an inch circumferentially outward from the hole centers indicated by the template (see Figure 1.3.1.1.1.1.1).

Sketch showing relocated hole centers in relation to indicated hole centers.

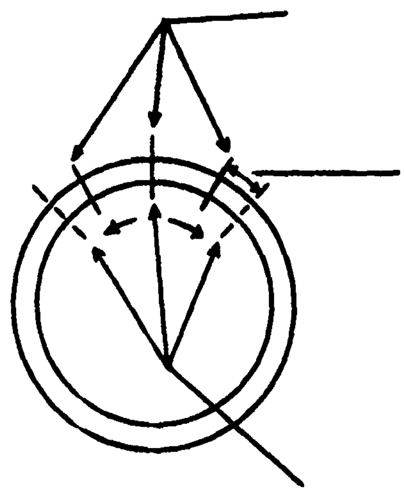


FIGURE 1.3.1.1.1.1.1

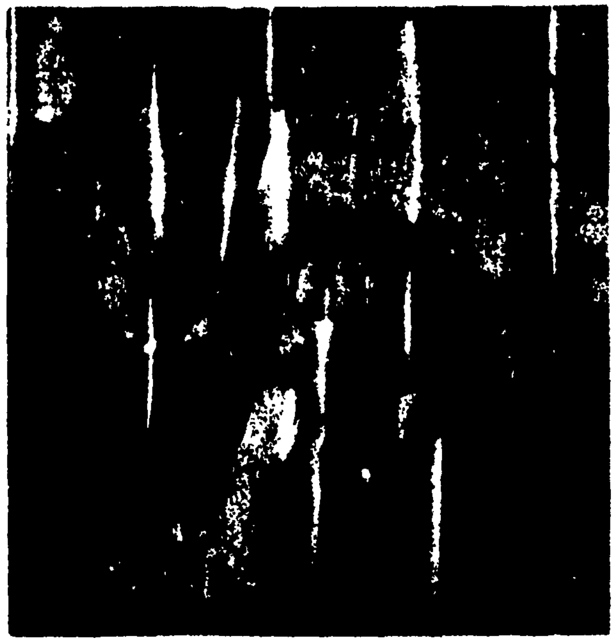
The holes of series six and seven were drilled using a table drill press (see Figure 1.3.1.1.1.1.2).

For series eight, the six test holes were machined using a 5/64 inch standard straight shank twist drill bit to drill each pilot hole, followed by a 3/32 inch standard straight shank twist drill bit for each final test hole. The series eight holes were drilled using a table drill press.

Photographs of 1 1/2" Pipe Tap
Construction Methods

FIGURE 1.3.1.1.1.1.2

TEMPLATE



TEMPLATE BEING USED
TO MARK HOLES

DRILLING HOLES USING
ELECTRIC HAND DRILL METHOD

DRILLING HOLES USING
VERTICAL DRILL PRESS METHOD

1.3.1.1.1.2 Deburring Procedure, Method 1

The method used on series one through series seven, employed a 5/64 inch standard straight shank twist drill bit to remove burrs.

The drill bit was sharpened to obtain a point angle[1] of 176°. It was then attached to an electric hand drill and inserted through the hole in the pipe directly opposite the hole to be deburred. Once inside the pipe, the drill bit was rotated around the perimeter of the hole to be deburred, with the lip[2] against the pipe wall, until the burrs were removed (see Figure 1.3.1.1.1.2.1).

Correct location of the drill bit was determined visually, through a third hole. To insure that all burrs had been removed, a 5/64 inch allen wrench was inserted in the hole, in the same manner as the drill bit, and used to feel the deburred hole perimeter for burrs (see Figure 1.3.1.1.1.2.1).

1.3.1.1.1.3 Deburring Procedure, Method 2

The second method of deburring, used for series number eight, started by drilling a pilot hole 1/64 of an inch smaller than the final test hole size. Therefore, when the test hole was drilled, most of the burrs were removed.

A wooden dowel containing sandpaper (see Figure 1.3.1.1.1.2.1), was attached to an electric hand drill by a threaded shaft and was rotated inside the pipe. The sandpaper then removed the remaining burrs. The first step in using the wooden dowel, employed a piece of 40 grit sandpaper for 15 seconds at approximately 25% of the electric hand drill's no load speed of 2200 RPM, and increased the speed approximately 25% every 15 seconds until full speed was obtained. Step two used a new sheet of 40 grit sandpaper at full speed for one minute. The final two steps were similar, with the only exception being that 80 grit sandpaper was employed instead of 40 grit.

[1] Point angle - the angle included between the cutting edges (lips) of a standard straight shank twist drill bit. Machinery Handbook, eighteenth edition, page 1572.

[2] Lip - cutting edge of a standard straight shank twist drill bit. Machinery Handbook, eighteenth edition, page 1572.

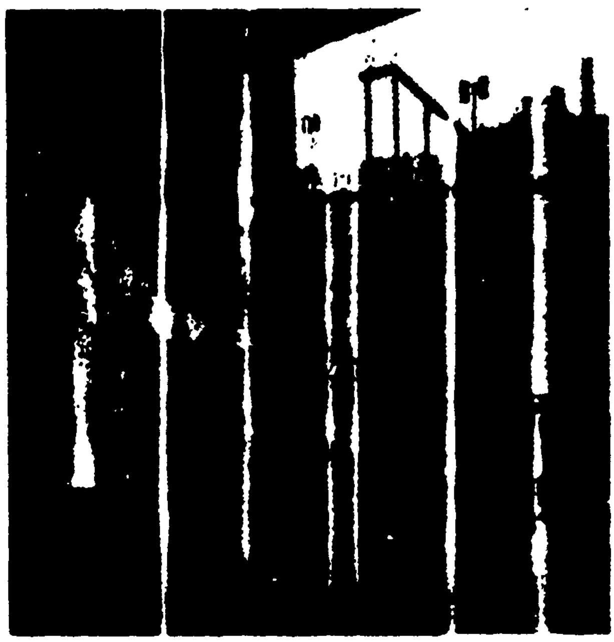
Photographs of 1 1/2" Pipe Tap Hole
Deburring Methods

FIGURE 1.3.1.1.1.2.1

DEBURRING METHOD NUMBER
ONE (SIMULATED)

CHECKING FOR BURRS
(SIMULATED)

END VIEW OF TOOL USED
IN DEBURRING METHOD NUMBER TWO



DEBURRING TOOL IN USE

1.3.1.1.2 1/2 Inch Tubing Size

1.3.1.1.2.1 Drilling Procedure

Prior to drilling, a pressure tap manifold was developed (see Figure 1.3.1.1.2.1.1). This manifold was also used as a template for marking the holes to be drilled in the test tubing. Two pieces of 1 1/2 inch square bar stock, 4 1/2 inches in length, were used as the construction material. The two pieces were bolted together using two 1/4 inch bolts, 3 1/2 inches long. With the two pieces bolted together, a 9/16 inch diameter hole was drilled through the center of the assembly, perpendicular to the assembly holes. A 5/64 inch diameter hole was then drilled 60° on either side of the surfaces between the two halves measured with the vertex of the angle at the center of the 9/16 inch diameter hole and the protractor perpendicular to the 9/16 inch diameter hole axis. A flat was machined perpendicular to the axis of each 5/64 inch diameter hole at the outer edge of the manifold. The holes were countersunk and tapped to accomodate a number four (1/4 inch) pipe to 37° flare tube fitting. Gaskets of neoprene rubber were glued on to the machined surface, on each half of the manifold, inside the 9/16 inch diameter hole. With the manifold clamped to the test tubing, a 5/64 inch diameter drill bit was inserted in each manifold port, and rotated to remove the neoprene covering each manifold port. A line was stamped on each half of the manifold parallel to assembly bolts, and directed at the center of the 9/16 inch diameter hole. These lines were used for alignment (see Figure 1.3.1.1.2.1.1).

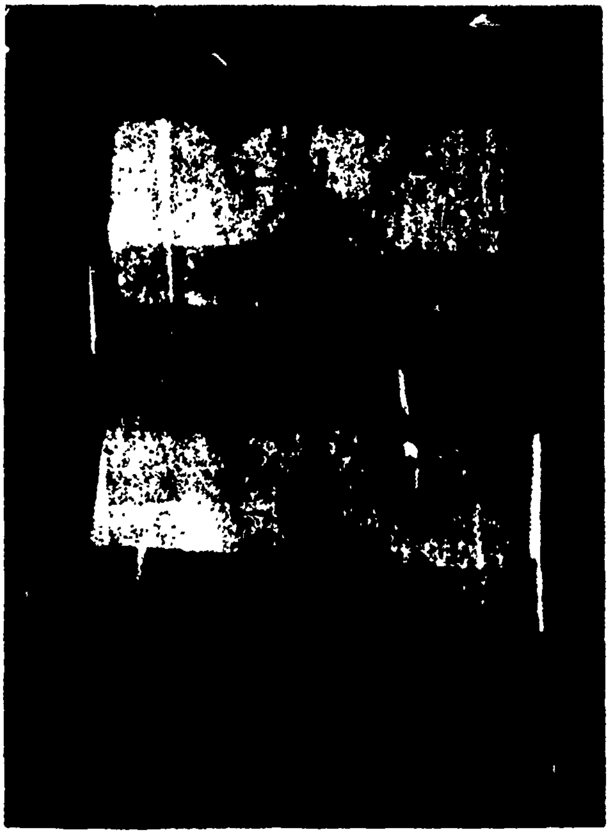
Seven series of holes, consisting of four holes per series, were drilled in a 22 inch length of 1/2 inch (.365 inch I.D.) nominal size seamless steel tubing. Radial locations for these holes were determined by the previously mentioned manifold. With the manifold clamped in place, an electric engraving pencil was used to make alignment marks on the tubing corresponding to those on the manifold and along the edge of the manifold (see Figure 1.3.1.1.2.1.1). The manifold fittings were then removed and a 5/64 inch diameter drill bit, attached at an electric drill, was inserted in each 5/64 inch diameter hole and rotated a sufficient amount to mark the tubing (see Figure 1.3.1.1.2.1.2). The manifold was then removed. A Dremel Moto-Tool with a 1/32 inch diameter drill bit installed, was used to drill hole number one. Hole number one was then deburred (see deburring procedure, Section 1.3.1.1.2.2). After hole number one was deburred, holes two, three, and four were also drilled with the 1/32 inch drill bit.

Series one was then ready for study. Series two through four were drilled and deburred in an identical manner. In series five, all holes were drilled with the 1/32 inch drill bit and deburred. For series six and seven, all holes were deburred, but the hole sizes varied. Hole number one was 1/32 inch in diameter, hole number two was 15/64 inch in diameter, hole number three was 1/16 inch in diameter, and hole number four was 1/8 inch in diameter.

Series number one was placed 2 inches upstream from the tubing exit, and each additional series was placed in sequence, 2 inches upstream from previous series, Selection of tap locations was based upon current work in ISO/TC-131/SC-8.

Photographs of 1/2 Inch Tubing Tap Hole
Construction Methods

FIGURE 1.3.1.1.2.1.1



PRESSURE TAP
MANIFOLD

ELECTRIC ENGRAVING
PENCIL

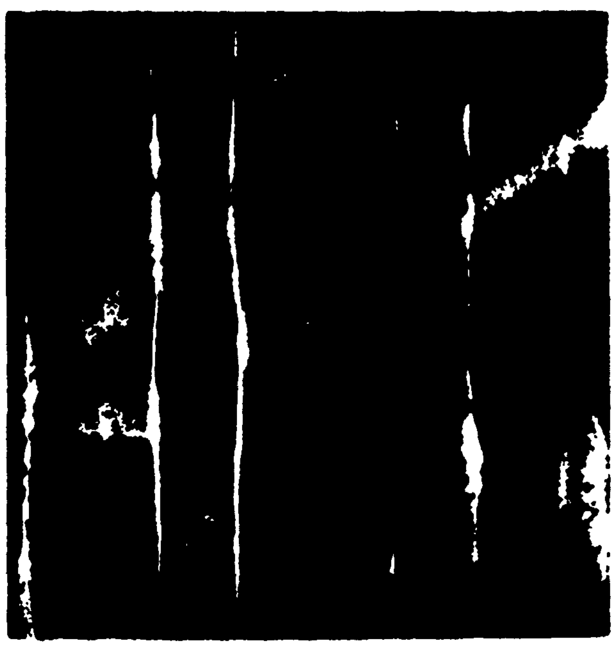
VERTICAL AND HORIZONTAL
ALIGNMENT MARKS, USED
TO INSURE CONTINUITY PRESSURE
FROM TAPS THROUGH MANIFOLD
AFTER REINSTALLING MANIFOLD
ON TUBING

Photographs of 1/2 Inch Tubing Tap Hole
Construction Methods

FIGURE 1.3.1.1.2.1.2

MARKING TUBING THROUGH PRESSURE TAP MANIFOLD

MARKS MADE IN TUBING THROUGH PRESSURE TAP MANIFOLD



DRILLING TAP HOLES WITH MOTO-TOOL

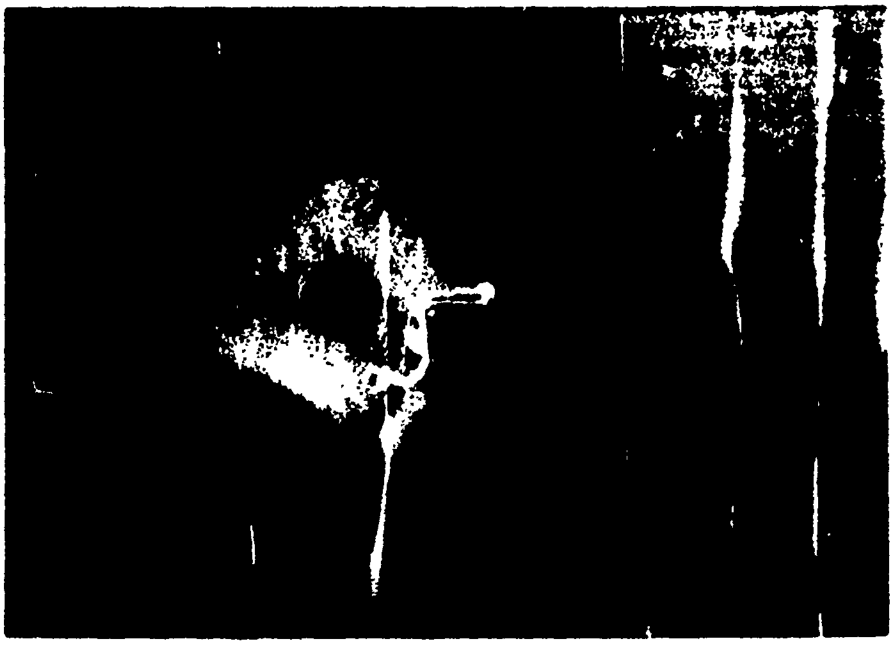
1.3.1.1.2.2 Deburring Procedure

Deburring required a special tool. This was constructed by sawing a slot 1 1/2 inches long and 1/32 inch wide in a 1/4 inch threaded shaft, thirty-two inches long. A piece of 80 grit sandpaper, 1 3/4 inches square, was folded in half and inserted in the slot of the threaded shaft with the 1 3/4 inch dimension parallel to the shaft's axis. The sandpaper was folded back to wrap around the threaded shaft clockwise, when viewed from the slotted end of the shaft. A piece of foam rubber was placed under each edge of the sandpaper to add support (see Figure 1.3.1.1.2.2.1).

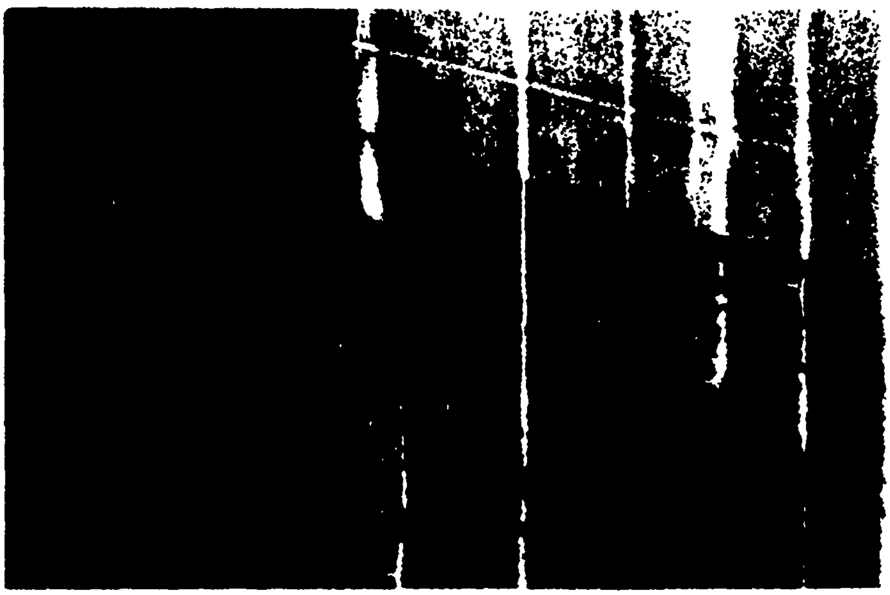
The distance from the hole to be deburred to the upstream entrance to the tubing was measured and marked on the threaded shaft with a piece of masking tape (see Figure 1.3.1.1.2.2.1). Therefore, proper positioning was assured when the tubing entrance was kept between the two edges of the masking tape. The threaded shaft was rotated using a 1/4 inch drill, rated at a no load speed of 2200 RPM, for approximately 1 minute. Burr removal was assured by tests conducted on sample pieces, prior to deburring the test tubing, and by inspection of test pipe after it was cut into sections.

Photographs of 1/2 Inch Tubing Tap Hole
Deburring Methods

FIGURE 1.3.1.1.2.2.1



END VIEW OF DEBURRING TOOL



DRILL WITH DEBURRING TOOL SHAFT INSTALLED AND SHOWING
MASKING TAPE DEPTH MARKINGS

1.3.1.2 Laboratory Tests

The two pipes described in Section 1.3.1.1 were connected to respective variable flow hydraulic supplies in order to measure the pressure differentials between the reference tap hole in each circumferential series and the other five holes. All differential pressures were observed on a single differential pressure gauge which was connected between the desired tap holes with a manually operated valve scheme. This section described the manifold which communicated the internal pipe pressures to the instrumentation. It also contains the details of the test procedure and the results.

1.3.1.2.1 1 1/2 Inch Pipe Test Set-Up

Prior to testing, a pressure tap manifold was developed (see Figure 1.3.1.2.1.1). The manifold was constructed from two pieces of 2 inch square bar stock, measuring 5 3/4 inches in length. The two pieces were bolted together using two 3/8 inch bolts. With the two pieces bolted together, a 15/16 inch hole was bored through the center of the assembly, perpendicular to the assembly bolts. A 3/16 inch diameter hole was then drilled through the center of the assembly, parallel to the assembly bolts. A 3/16 inch diameter hole was also drilled 30° on either side of each 3/16 inch center hole, measured with the vertex of the angle at the center of the 1 15/16 inch diameter hole and the protractor perpendicular to the 1 15/16 inch diameter hole axis. A flat was machined perpendicular to the axis of each 3/16 inch diameter hole at the outer edge of the manifold and the holes were tapped to accomodate a number four (1/4 inch) pipe to 37° flare tube fitting. Gaskets of neoprene rubber, with 3/16 inch diameter holes punched out to align with the 3/16 inch diameter holes mentioned above, were glued to the machined surface, on each half of the manifold, inside the 1 15/16 inch hole.

For the test set up, the 50 inch long, 1 1/2 inch schedule 80 welded, black iron test pipe was installed into the FPI high flow supply line. A 2 1/2 gallon bladder type accumulator, precharged to 10 psig, was installed upstream from test pipe. A turbine flowmeter was installed between the downstream side of the test pipe and the reservoir (see Figures 1.3.1.2.1.1, 1.3.1.2.1.2, and 1.3.1.2.1.3).

The first series of holes, series number one, were drilled six inches from the downstream end of the test pipe. Each additional series was drilled four inches upstream from the previous series, after the previous series had been tested[1]. Hole number one in each series was deburred as previously described in the deburring procedure of Section 1.3.1.1.1.2.

[1] Selection of tap locations based upon current work in ISO/TC-131/SC-8

To install the pressure tap manifold, allen wrenches were inserted through the ports of the manifold to insure proper alignment with one of the holes of the test pipe. Once properly aligned, the manifold was bolted together. This procedure was used for series number one through eight. It should be noted that for series number eight, an allen wrench was used only on the center hole of each manifold half. This was due to the small size of the holes in the test pipe.

The test holes of the pipe were identified using metal stamps numbers one through six. The location of hole number one, in each series, was chosen at random.

For hole number one, a 1/4 inch hydraulic hose was used to connect the manifold to two 1/4 inch needle valves. The outlet of one needle valve was connected to the high side of a differential pressure gauge, and the other needle valve outlet was connected to the low side of the same gauge.

One quarter inch hydraulic hoses were also used to connect the manifold fittings for holes two through six to the bank of five 1/4 inch needle valves. The outlet of each of the five valves were connected to a common 3/8 inch pipe. This pipe was then connected to two 1/4 inch needle valves. The outlets of these needle valves were connected to the same differential pressure gauge in the same manner as those connected to hole number one.

Whenever differential pressure was measured, the normal or positive condition was considered to be when hole number one was open to the high side of the differential pressure gauge, and holes number two through number six were open to the low side. When the differential pressure gauge indicated a negative pressure, the system of valves around the gauge made it possible to produce an upscale indication on the gauge by opening and closing the necessary valves.

INSTRUMENTATION

1. Pressure Gauge

   Marsh Mastergauge type 101
   0-100 psig in 1 psig increments

2. Differential Pressure Gauge

   Barton Instrument Corporation (with modified scale)
   - .5 to +6.5 psig in .05 psig increments

   Barton Instrument Corporation
   0-30 psid in .25 psid increments

3. Temperature Indicator

   Marsh Master Thermo
   -100°F to 150°F in 2°F increments

4. Flow Meter

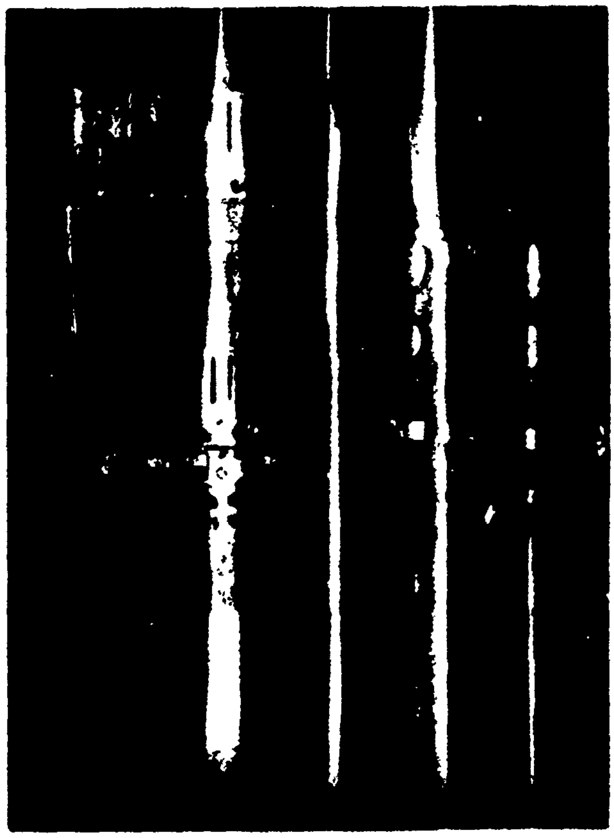
   A. O. Smith
   60-425 gpm 3 inch turbine flowmeter
   used with a Beckman frequency counter
   Model number - 7360-58
   Serial number- 4340

PHOTOGRAPHS OF PRESSURE MEASUREMENTS TEST FOR 1 1/2 INCH PIPE

FIGURE 1.3.1.2.1.1

TEST SET-UP

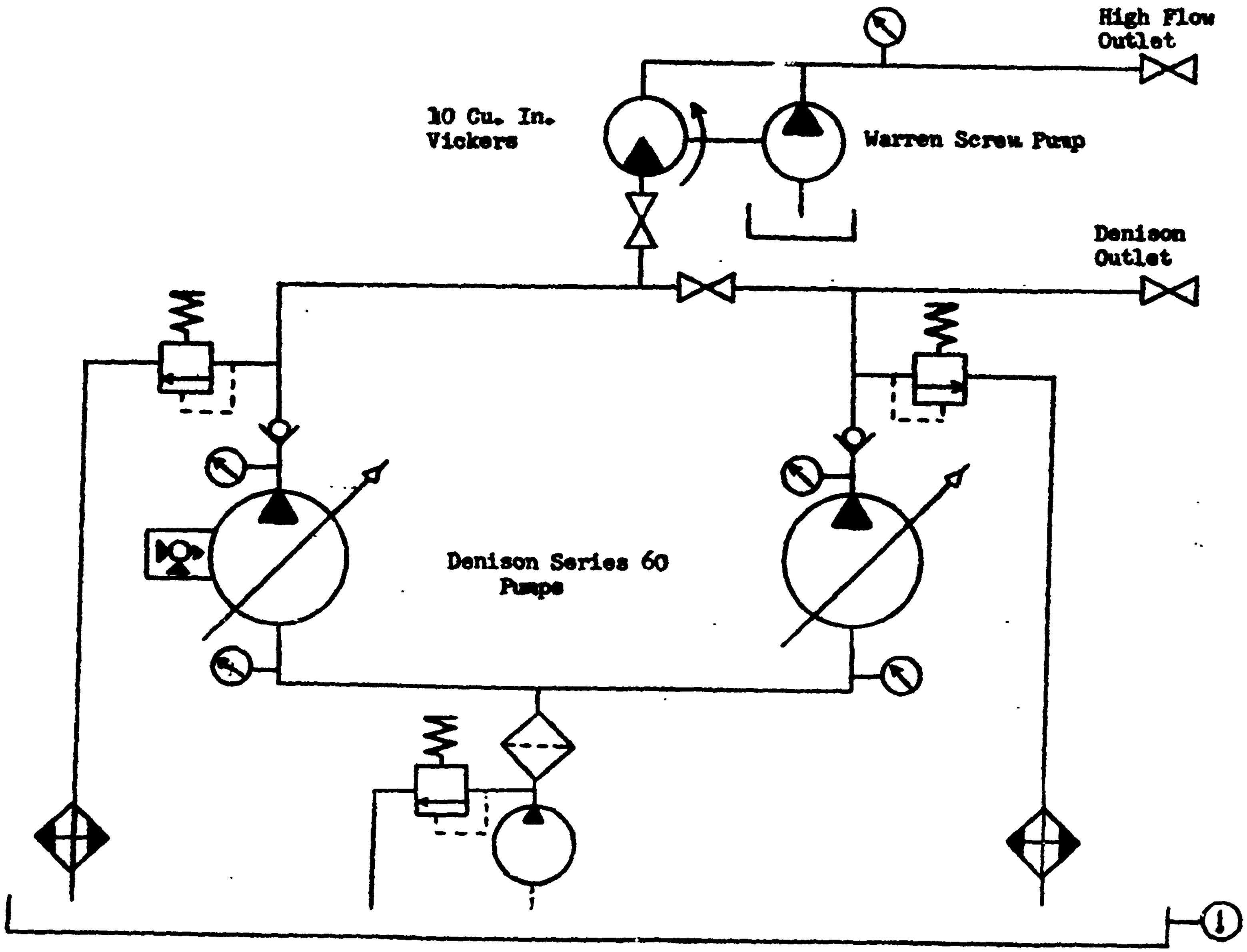
PRESSURE TAP MANIFOLD



FREQUENCY COUNTER AND REMOTE CONTROL CONSOLE

Hydraulic Schematic For FPI 300 HP Test Supply

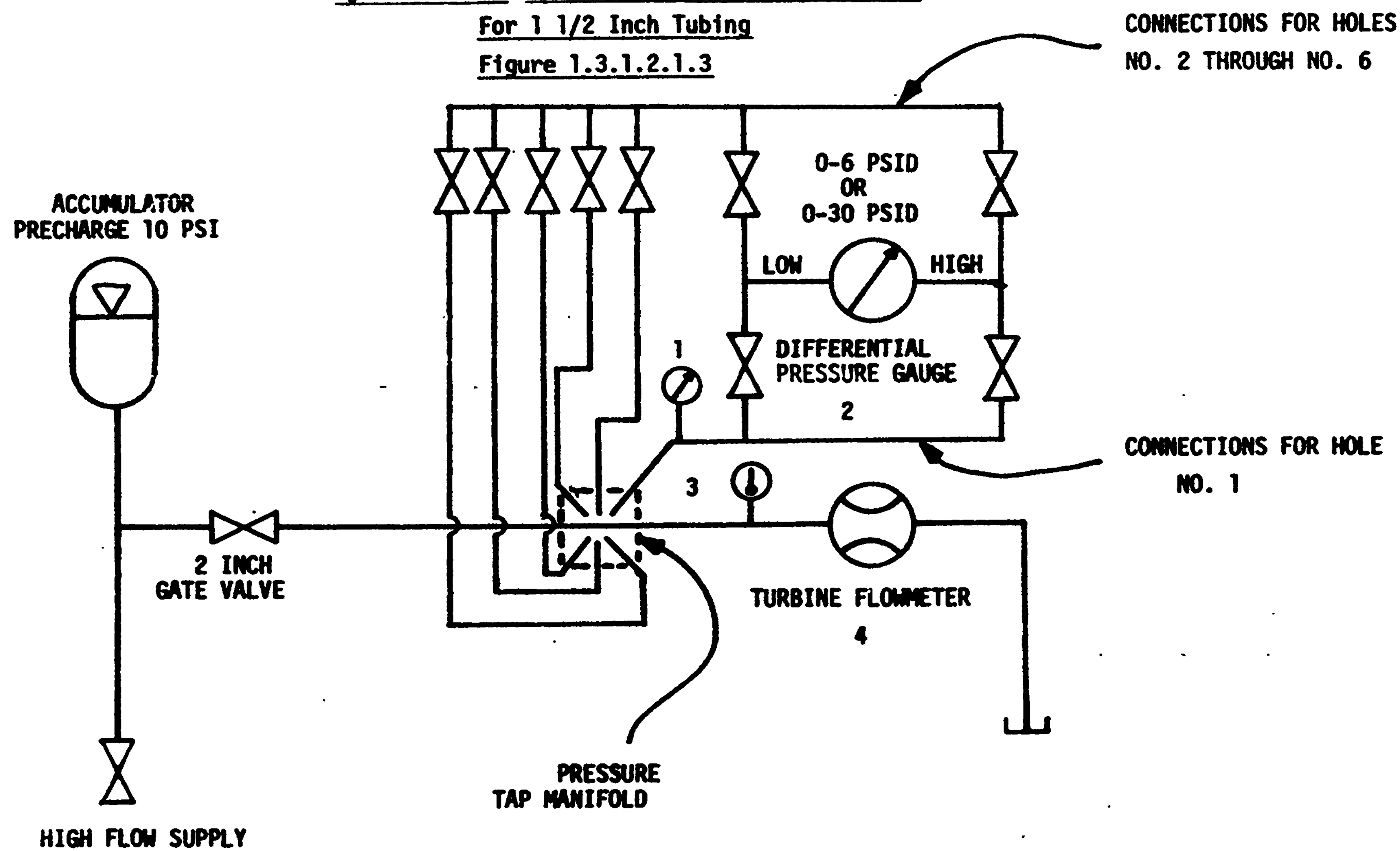
Figure 1.3.1.2.1.2



Hydraulic Scheratic For Tap Hole Quality Test

For 1 1/2 Inch Tubing

Figure 1.3.1.2.1.3



1.3.1.2.1.1 Procedure for Testing

With the set up completed, flow was introduced to the test pipe. At each series of test holes, six different flow rate set points were investigated; 98.8 gpm, 126.2 gpm, 189.3 gpm, 253.6 gpm, 316.7 gpm, and 379.8 gpm. Which yielded fluid velocities of 18.3 ft/sec, 23.4 ft/sec, 35.1 ft/sec, 47.0 ft/sec, 58.7 ft/sec, and 70.3 ft/sec respectively.

At each of the setpoints, hole number one was considered as the standard, because it was carefully deburred. Pressure at holes two through six were individually compared to the pressure at hole number one, by using a differential pressure gauge. When negative pressures were indicated, the settings of the valves located around the differential pressure gauge were reversed. This produced on upscale indication on the gauge, but was recorded as negative reading (refer to procedure for set up, Section 1.3.1.2.1). Each series was investigated in this manner.

In series one through series four, a 0 to 30 psid differential pressure gauge was used to make the comparisons. For series five through eight, a -0.5 to 6.5 psid differential pressure gauge was employed. The change in gauges was due to the low differential pressures observed in series five through eight.

Data Table 1.3.1.2.1.1.1

Test: Determination of Tap Hole Quality Effect on Pressure Measurement in Hydraulic Transmission Lines

Component: 1 1/2 inch schedule 80 welded black iron pipe with eight series of tap holes drilled. Hole number one in series one through four was a 5/32 inch diameter deburred hole, all other holes in series one through four were 5/32 inch diameter burred holes. In series five through eight, all holes were deburred, but varied in size. Series five contained 5/32 inch holes in all positions. Series six and seven consisted of the following varying diameter holes; hole one 1/2 inch, hole two 3/32 inch, hole three 21/64 inch, hole four 13/32 inch, hole five 5/32 inch, hole six 1/4 inch. Series eight had six 3/32 inch holes.

Dates: January 6, 1976 through January 20, 1976

Technician: L.A.L.

Series Number	Flow Meter HZ	Differential Pressure (psid) Holes 1-2	Holes 1-3	Holes 1-4	Holes 1-5	Holes 1-6	Line Press psig	Temp °F	Oil Velocity ft/sec	Flow Rate GPM
1	83	.25	.5	-.25	-.25	.5	3	115	18.3	98
1	106	.25	.75	-.25	-.25	1	4	120	23.4	126
1	159	.50	2	-.50	-.50	2.5	7	120	35.1	189
1	213	1	4	-.5	-.5	4.75	12	120	47.0	253
1	266	1.75	6.75	-1	-.75	7.75	17	120	58.7	316
1	319	2.5	10	-1.5	-1	11.25	24	120	70.3	379
2	83	.25	.5	0	.25	.25	4	120	18.3	98
2	106	.75	.75	0	.5	.5	4.5	120	23.4	126
2	159	4.75	2	-.25	1	1.25	8	120	35.1	189
2	213	4.75	3.5	-.75	2	2.25	13	125	47.0	253
2	266	2.50	5.75	-1	3.25	3.75	20	120	58.7	316
2	319	9.25	9	-1.5	4.75	5.5	28	120	70.3	379
3	83	0	0	0	0	0	4	122	18.3	98
3	106	0	0	.25	0	0	5	122	23.4	126
3	159	-.50	.5	.75	0	.5	10	120	35.1	189
3	213	-.75	1	1.5	.25	1	16	118	47.0	253
3	266	-1.25	2	2.75	.5	1.5	23	120	58.7	316
3	319	-2	3.25	4	1	2.75	32	122	70.3	379
4	83	0	.25	.25	.25	.25	4	124	18.3	98
4	106	.25	.5	.5	.5	.75	5	124	23.4	126
4	159	1	1.5	1.75	1.75	1.75	10	124	35.1	189
4	213	2	2.75	2.75	3	3.25	16	124	47.0	253
4	266	3.5	4.5	5.25	5.25	5.25	23	125	58.7	316
4	319	5.25	6.75	6.25	7.25	7.75	33	122	70.3	379

Series Number	Flow Meter HZ	Differential Pressure (psid) Holes 1-2	Holes 1-3	Holes 1-4	Holes 1-5	Holes 1-6	Line Press psig	Temp °F	Oil Velocity ft/sec	Flow Rate GPM
5	83	.05	.05	.05	.05	.05	4	120	18.3	98
5	106	.05	.05	.05	.05	.1	5	120	23.4	126
5	159	.25	.15	.15	.15	.15	9	120	35.1	189
5	213	.1	.1	.15	.1	.1	14	122	47.0	253
5	266	.05	.05	.15	.15	.15	21	122	58.7	316
5	319	.1	.05	.15	.15	.2	29	120	70.3	379
6	83	0	0	0	0	.05	4	120	18.3	98
6	106	.05	0	0	.05	.05	5	122	23.4	126
6	159	.45	.15	.15	-.1	.05	11	122	35.1	189
6	213	.6	.2	.2	-.25	.05	19	122	47.0	253
6	266	.95	.15	.35	-.4	.1	29	120	58.7	316
6	319	1.3	.1	-.1	-.05	.1	38	120	70.3	379
7	83	-.05	0	0	0	0	4	118	18.3	98
7	106	-.05	.1	.1	.05	.2	6	120	23.4	126
7	159	-.05	.15	.15	.05	.15	11	122	35.1	189
7	213	-.15	.05	.15	-.15	.05	18	122	47.0	253
7	266	-.25	-.15	.15	-.4	-.3	27	124	58.7	316
7	319	-.5	-.4	.15	-.75	-.6	42	120	70.3	379
8	83	.05	0	.25	.15	.2	4	118	18.3	98
8	106	-.1	0	.2	.1	.2	5	118	23.4	126
8	159	.15	0	.15	.1	.1	10	120	35.1	189
8	213	.1	.15	.15	.1	.05	17	122	47.0	253
8	266	.1	.15	.05	0	-.05	25	120	58.7	316
8	319	-.1	.15	-.2	.05	-.2	36	120	70.3	379

Photographs of 1 1/2 inch Pipe

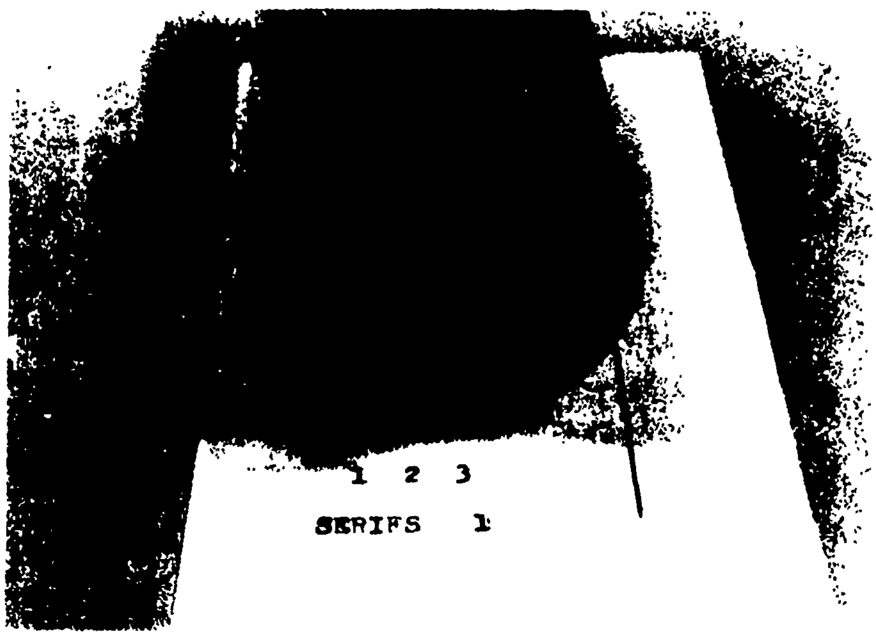
Scale - 1/16 inch equals 3/32 inch

Flow - in direction of arrow

Hole number - indicated by numbers below holes

Series number - labeled in photograph

FIGURE 1.3.1.2.1.4



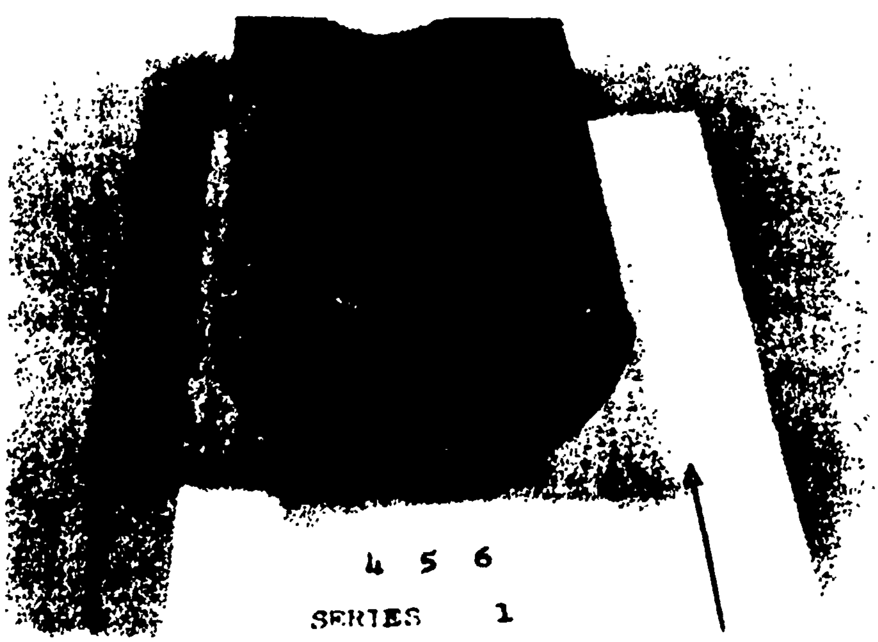


FIGURE 1.3.1.2.1.5

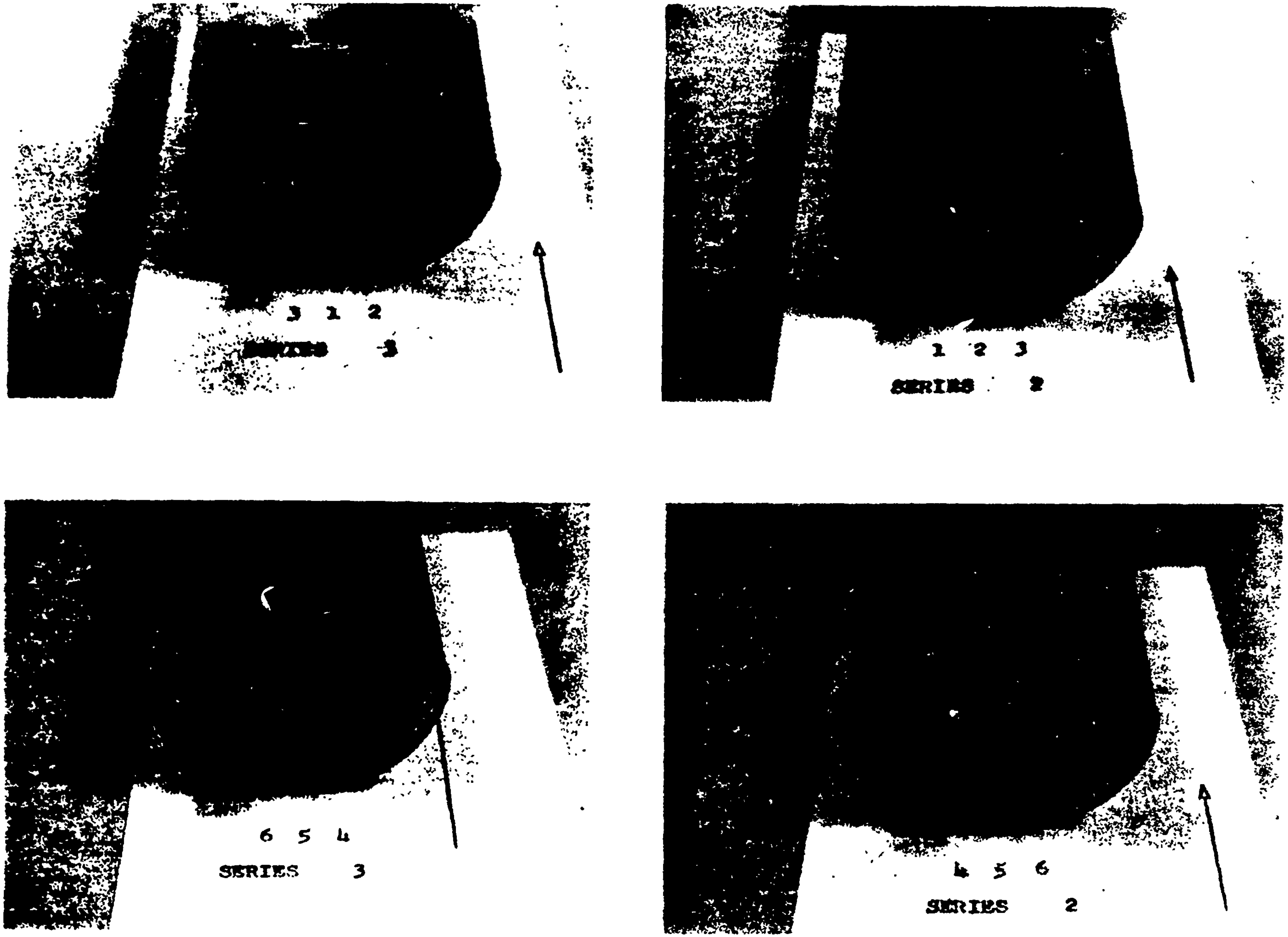


FIGURE 1.3.1.2.1.6

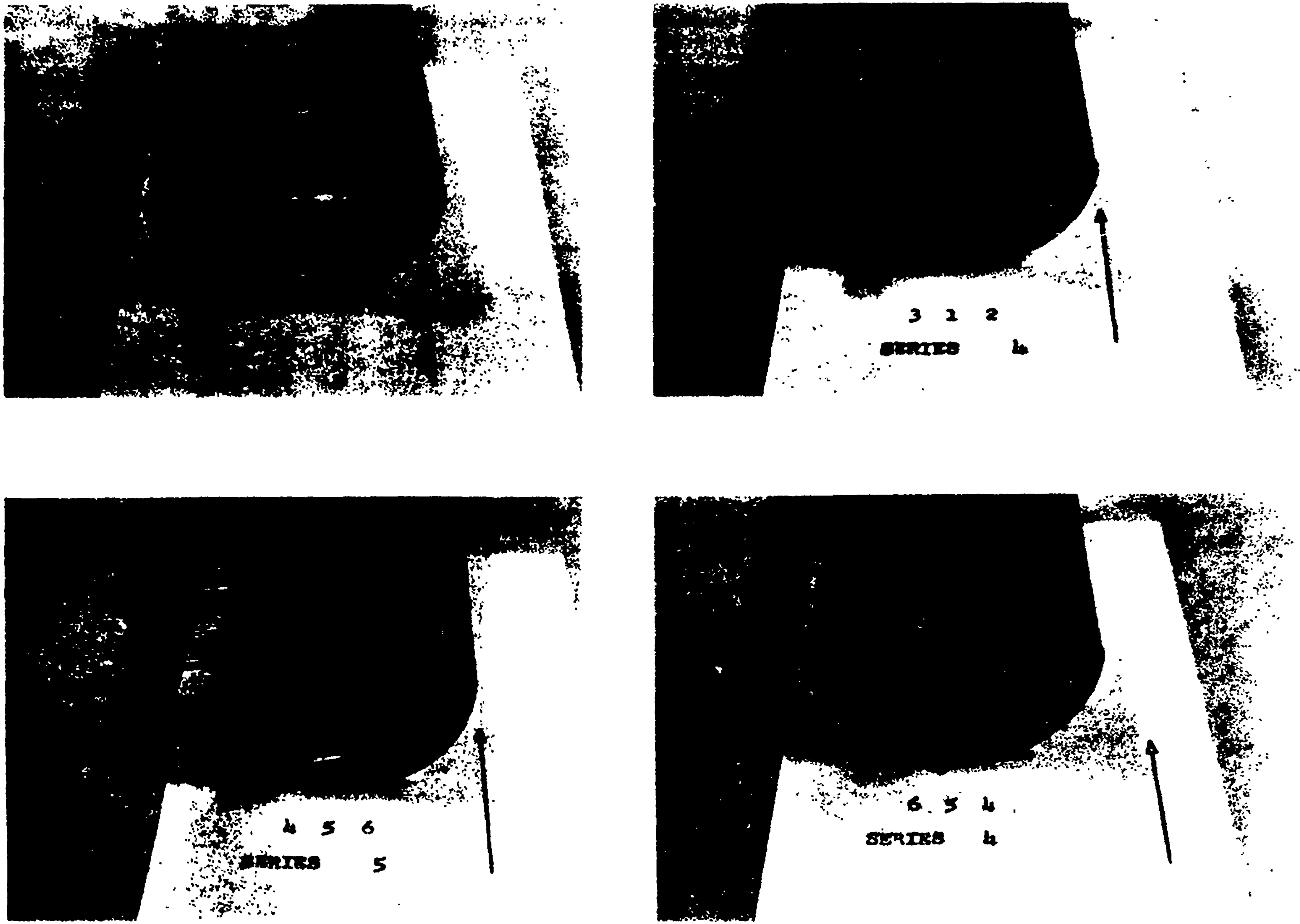


FIGURE 1.3.1.2.1.7

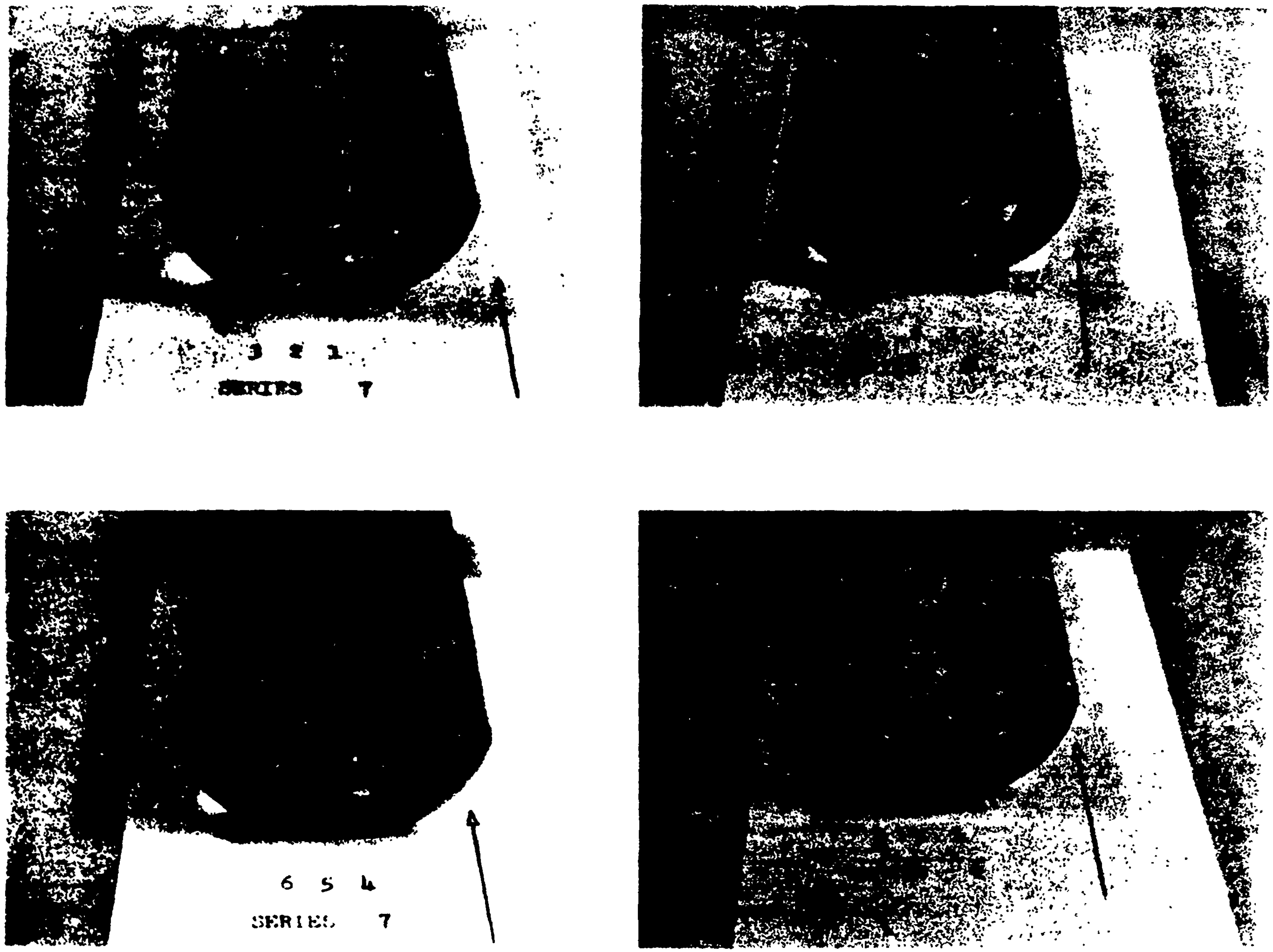
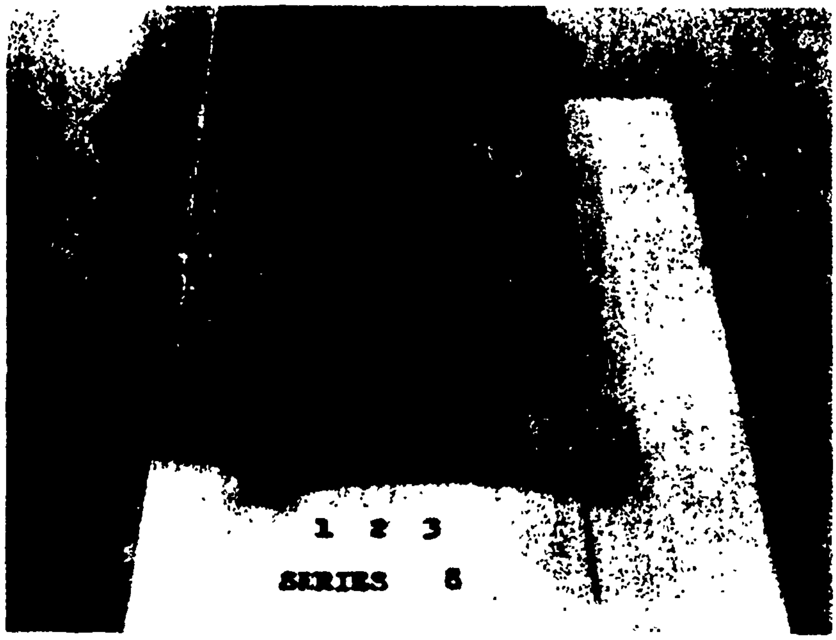
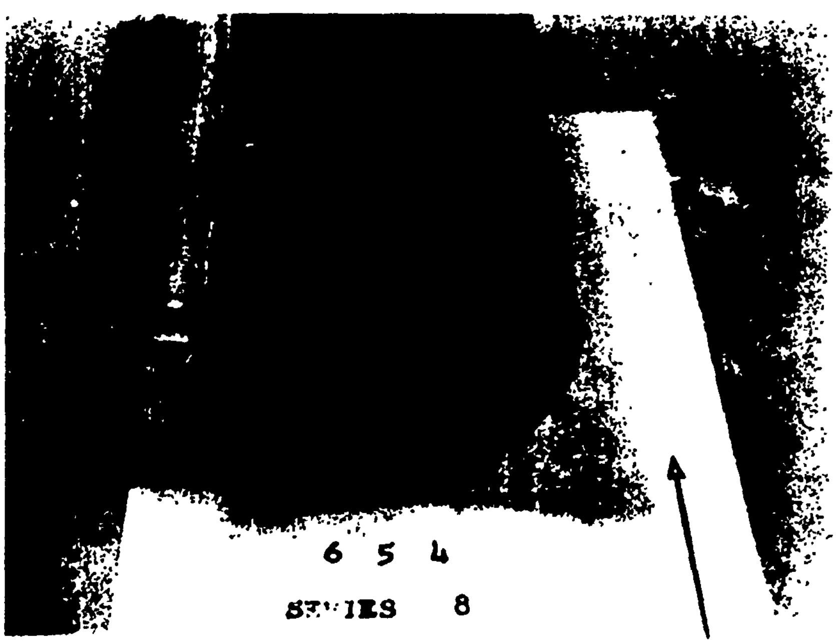


FIGURE 1.3.1.2.1.8





1.3.1.2.2 1/2 Inch Tubing Test Set-up

For the test set up, the 32 inch long, 1/2 inch seamless steel tubing was installed into the FPI 190 HP test cell number three pump supply line (see Figure 1.3.1.2.2.2).

The first series of holes, series number one, was drilled two inches from the downstream end of the test tubing. Each additional series was drilled two inches upstream from the previous series, after the previous series had been investigated. Selection of tap locations was based upon current work in ISO/TC-131/SC-8. Hole number one was deburred in each series, as previously described in the deburring procedure, Section 1.3.1.1.2.2.

To install the pressure tap manifold, care was taken to match the alignment marks as close as possible. Once pressure was applied to each series, the hose attached to each of the four manifold fittings was loosened a sufficient amount to allow hydraulic fluid to bleed off. This procedure assured continuity between the tap hole and the manifold fitting, due to the fact that the oil was flowing through when being bled off.

The test holes of the tube were identified using an electric marking pencil to scribe the numerals one through four for hole identification and Roman numerals I through VII were used to identify each series of holes.

For hole number one, a 1/4 inch hydraulic hose was used to connect the manifold to two 1/4 inch needle valves. The outlet of one needle valve was connected to the high side of a differential pressure gauge and the other needle valve outlet was connected to the low side of the same gauge.

One quarter inch hydraulic hoses were also used to connect the manifold fittings for holes two through four, to the bank of three 1/4 inch needle valves. The outlet of each of the three valves were connected to a common 3/8 inch pipe, this pipe was then connected to two 1/4 inch needle valves. The outlets of these needle valves were connected to the same differential pressure gauge in the same manner, as those connected to hole number one.

Whenever differential pressure was measured, the normal or positive condition was considered to be, when hole number one was open to the high side of the differential pressure gauge, and holes number two through number four were open to the low side. When the differential pressure gauge indicated a negative pressure, the system of valves around the gauge made it possible to produce an upscale indication on the gauge by opening and closing the necessary valves (see Figure 1.3.1.2.2.1).

INSTRUMENTATION

1/2 Tubing Test

Flowmeter

2.3 Vickers
Counter Beckman Model - 7360-58
Serial - 4340

Line Press

0-1000 in 10 psi increments
Mastergauge type 101
Jos. P. Marsh Corp.

ΔP

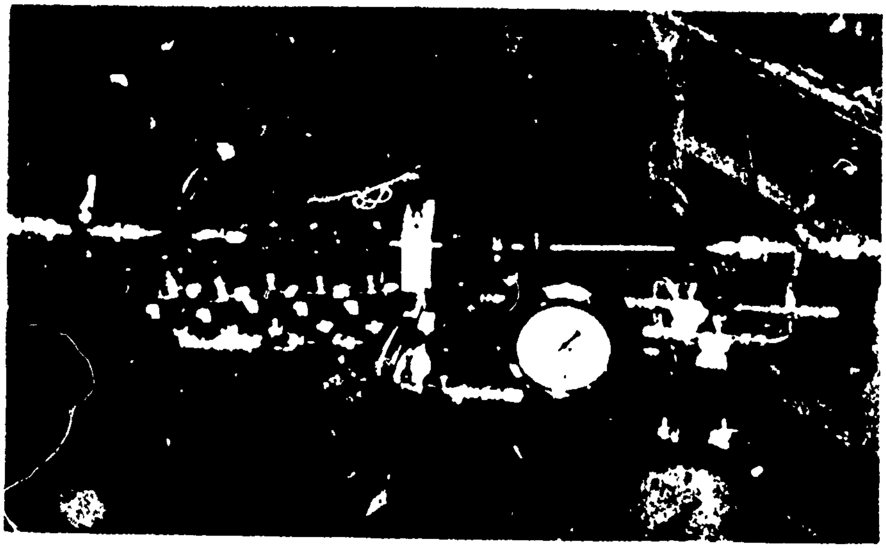
I T Barton
-.5 - 6.5 in .05 increments
Serial No. 227-72-516

Temperature

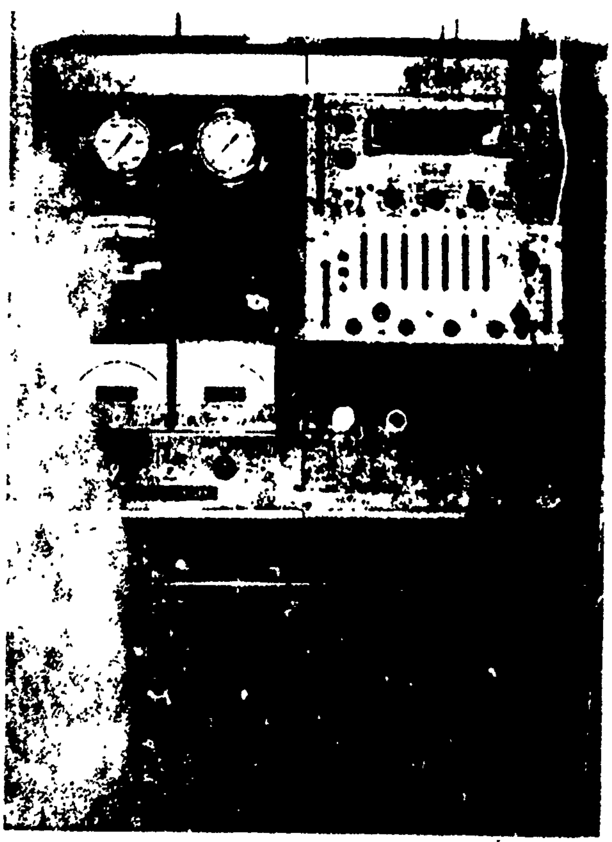
Weston Electrical Instrument Corporation
0 - 150°C in 1°C increments

PHOTOGRAPHS OF PRESSURE MEASUREMENT TEST FOR 1/2 INCH TUBING

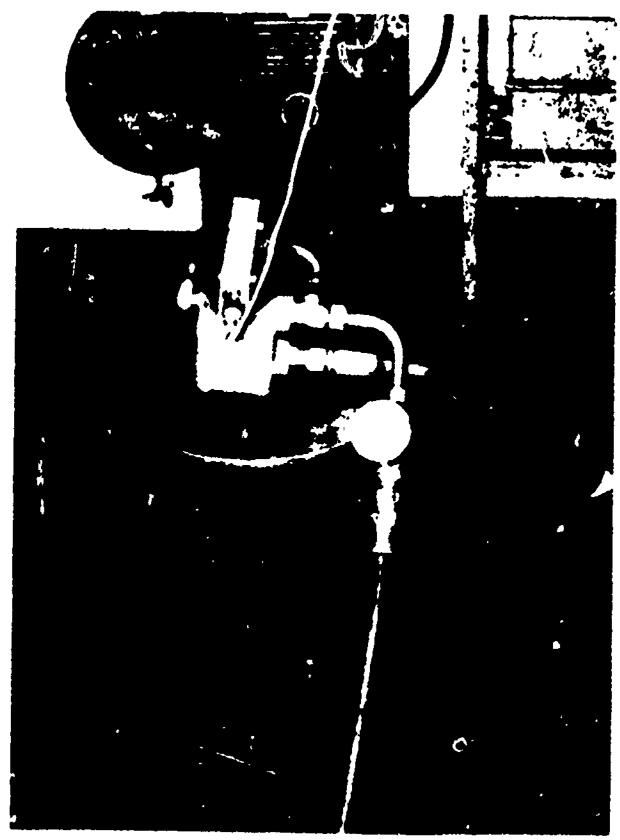
FIGURE 1.3.1.2.2.1



TEST SET-UP



FLOWM...

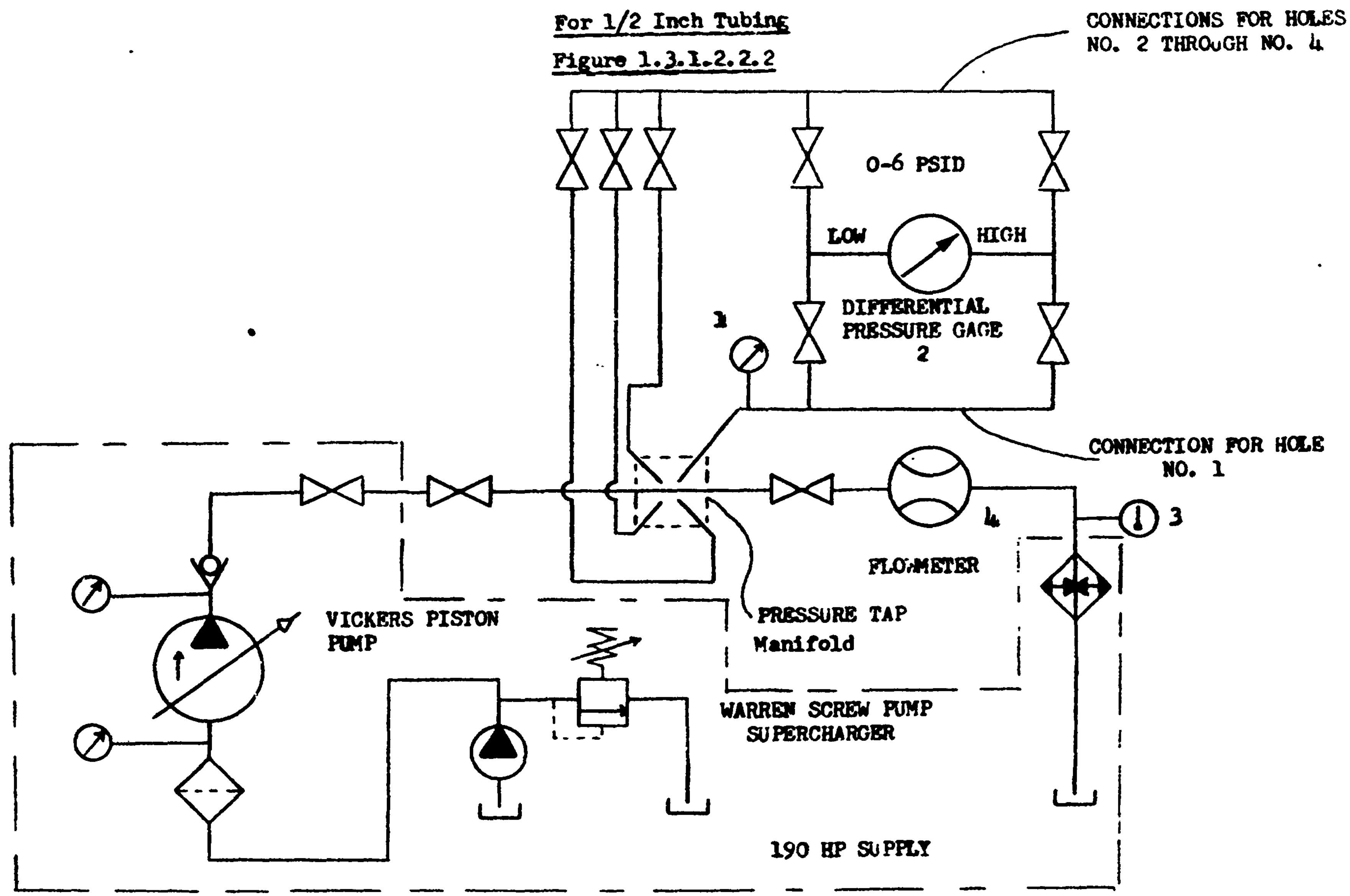


CONTROL CONSOLE

Hydraulic Schematic For Tap Hole Quality Test

For 1/2 Inch Tubing

Figure 1.3.1.2.2.2



1.3.1.2.2.1 Procedure for Testing

With the setup completed, flow was introduced to the test tubing. At each series of test holes, eight different flow rate set points were investigated; 4.8 gpm, 6.5 gpm, 9.7 gpm, 13.0 gpm, 16.2 gpm, 19.6 gpm, 21.2 gpm, and 22.8 gpm, which resulted in fluid velocities of 15 ft/sec, 20 ft/sec, 30 ft/sec, 40 ft/sec, 50 ft/sec, 60 ft/sec, 65 ft/sec, and 70 ft/sec respectively. At each of the set points, hole number one was considered as the standard, because it was carefully deburred. Pressures at holes two through four were individually compared to the pressure at hole number one, by using a differential pressure gauge. When negative pressures were indicated, the settings of the valves, located around the differential pressure gauge, were reversed. This produced an upscale indication on the gauge, but was regarded as a negative value (refer to procedure for set up in Section 1.3.1.2.2). Each series was investigated in this manner.

Data Table 1.3.1.2.2.1.1.

Test: Determination of Tap Hole Quality Effect on Pressure Measurement in Hydraulic Transmission Lines

Component: 1/2 inch seamless steel tubing with seven series of tap holes drilled. Hole number one in series one through four, was a 1/32 inch diameter deburred hole, all other holes in series one through four were 1/32 inch diameter burred holes. In series five through seven all holes were deburred, but varied in size. Series five contained 1/32 inch diameter holes in all positions. Series 6 and 7 consisted of the following varying diameter holes: hole one 1/32, hole two 15/64, hole three 1/16, hole four 1/8.

Dates: February 25, 1976 through March 3, 1976

Technician: L.A.L.

Series Number	Flow Meter HZ	Differential Pressure PSID 1-2	Differential Pressure PSID 1-3	Differential Pressure PSID 1-4	Line Pressure PSIG	Temp °C	Oil Velocity ft/sec	Flow Rate GPM
1	1043	.15	.20	0	60	43	15	4.88
1	1391	.15	.20	0	65	44	20	6.52
1	2087	.20	.75	0	70	44	30	9.77
1	2782	.25	.70	-.05	80	45	40	13.00
1	3478	.45	2.30	-.20	110	45	50	16.29
1	4173	.75	3.70	-.20	140	45	60	19.55
1	4521	.95	4.40	-.25	160	43	65	23.18
1	4869	1.10	5.20	-.20	170	43	70	23.80
2	1043	-.05	.1	.05	40	42	15	4.88
2	1391	0	0	.05	50	40	20	6.52
2	2087	-.15	.1	.15	60	44	30	9.77
2	2782	-.25	.15	.30	90	40	40	13.00
2	3478	-1.65	.40	.75	110	45	50	16.29
2	4173	-2.45	.60	1.20	140	44	60	19.55
2	4521	-2.95	.75	1.35	160	43	65	23.18
2	4869	-3.45	.95	1.65	180	42	70	23.80
3	1043	0	0	.05	40	44	15	4.88
3	1391	-.10	-.05	.05	40	46	20	6.52
3	2087	-.20	-.10	.10	60	46	30	9.77
3	2782	-.45	-.55	.40	90	47	40	13.00
3	3478	-.80	-1.50	.95	110	47	50	16.29
3	4173	-1.10	-2.25	1.50	140	46	60	19.55
3	4521	-1.30	-2.60	1.80	160	45	65	23.18
3	4869	-1.50	-3.05	2.20	180	44	70	23.80

Table 1.3.1.2.2.1.1

Continued

Series Number	Flow Meter HZ	Differential Pressure PSID 1-2	Differential Pressure PSID 1-3	Differential Pressure PSID 1-4	Line Pressure PSID	Temp °C	Oil Velocity ft/sec	Flow Rate GPM
4	1043	.05	.05	.1	40	40	15	4.88
4	1391	.05	0	.15	50	41	20	6.52
4	2087	.25	-.15	.40	70	42	30	9.77
4	2782	.50	-.40	.85	90	43	40	13.00
4	3478	1.95	-1.10	1.95	120	43	50	16.29
4	4173	3.45	-1.70	3.20	160	43	60	19.55
4	4521	4.20	-2.05	3.70	170	42	65	23.18
4	4869	4.85	-2.35	4.30	200	40	70	23.80
5	1043	.05	.15	.05	40	35	15	4.88
5	1391	0	.05	0	50	36	20	6.52
5	2087	0	.05	0	80	37	30	9.77
5	2782	0	.05	0	100	37	40	13.00
5	3478	0	.05	0	130	37	50	16.29
5	4172	0	.05	.05	170	37	60	19.55
5	4521	0	.05	.05	190	37	65	23.18
5	4869	0	.10	.05	220	36	70	23.80
6	1043	0	0	0	50	35	15	4.88
6	1391	0	0	0	60	36	20	6.52
6	2087	-.05	0	0	80	36	30	9.77
6	2782	-.05	.05	.05	100	37	40	13.00
6	3478	-.10	.15	.15	130	39	50	16.29
6	4172	-.10	.20	.20	170	36	60	19.55
6	4521	-.10	.20	.20	200	33	65	23.18
6	4869	-.10	.25	.25	230	34	70	23.80
7	1043	0	0	0	40	40	15	4.88
7	1391	-.05	0	0	50	40	20	6.52
7	2087	-.05	.05	.10	70	40	30	9.77
7	2782	-.05	.10	.15	100	40	40	13.00
7	3478	0	.20	.25	130	39	50	16.29
7	4172	-.05	.35	.45	170	39	60	19.55
7	4521	-.05	.40	.55	200	38	65	23.18
7	4869	-.05	.55	.70	230	38	70	23.80

Photographs of 1/2 inch Tube Sections

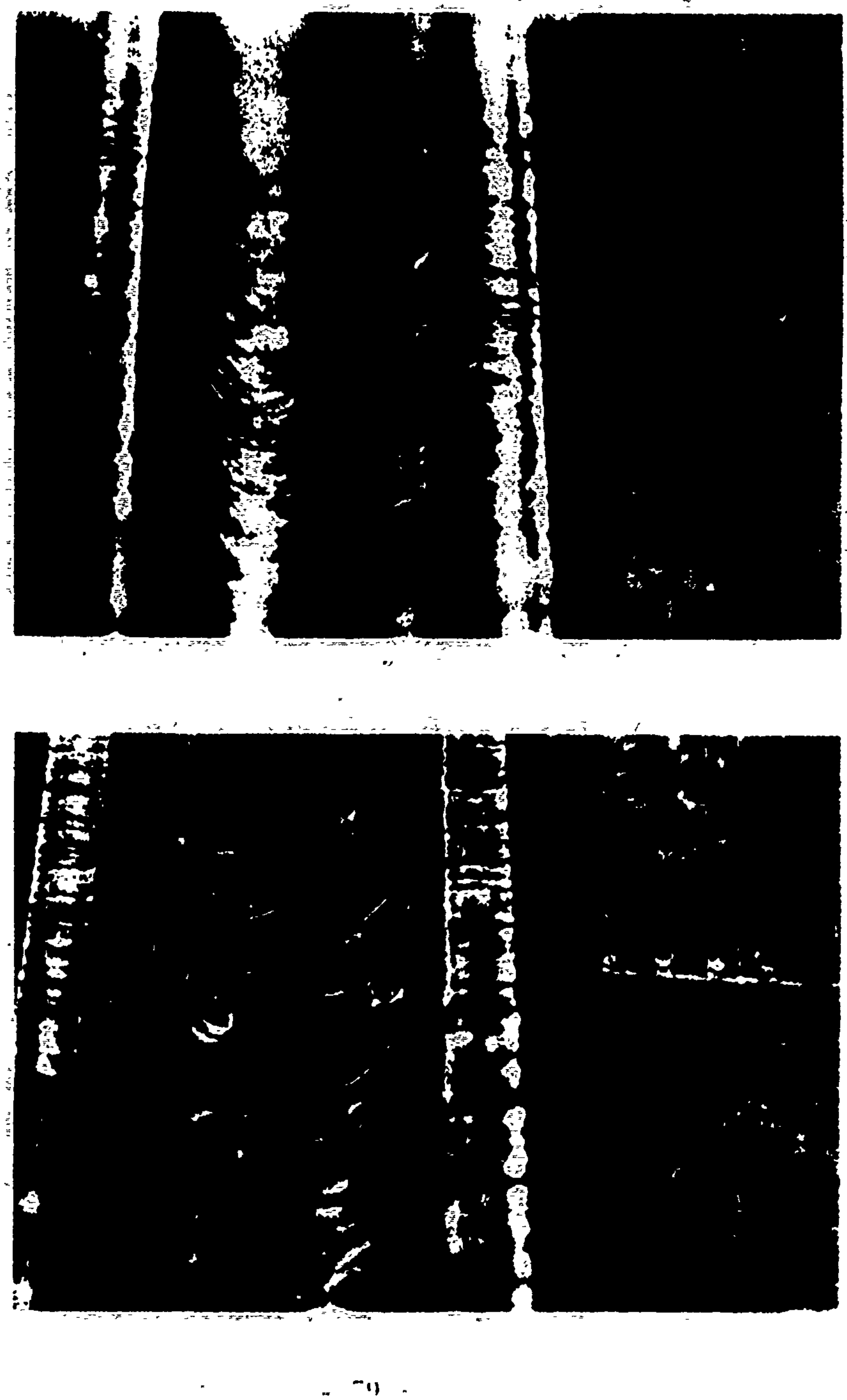
Scale in upper right corner marked in 1/16 inch divisions

Flow indicated by direction of arrow

Roman numerals indicate series number

Standard numerals indicate hole number

FIGURE 1.3.1.2.2.3



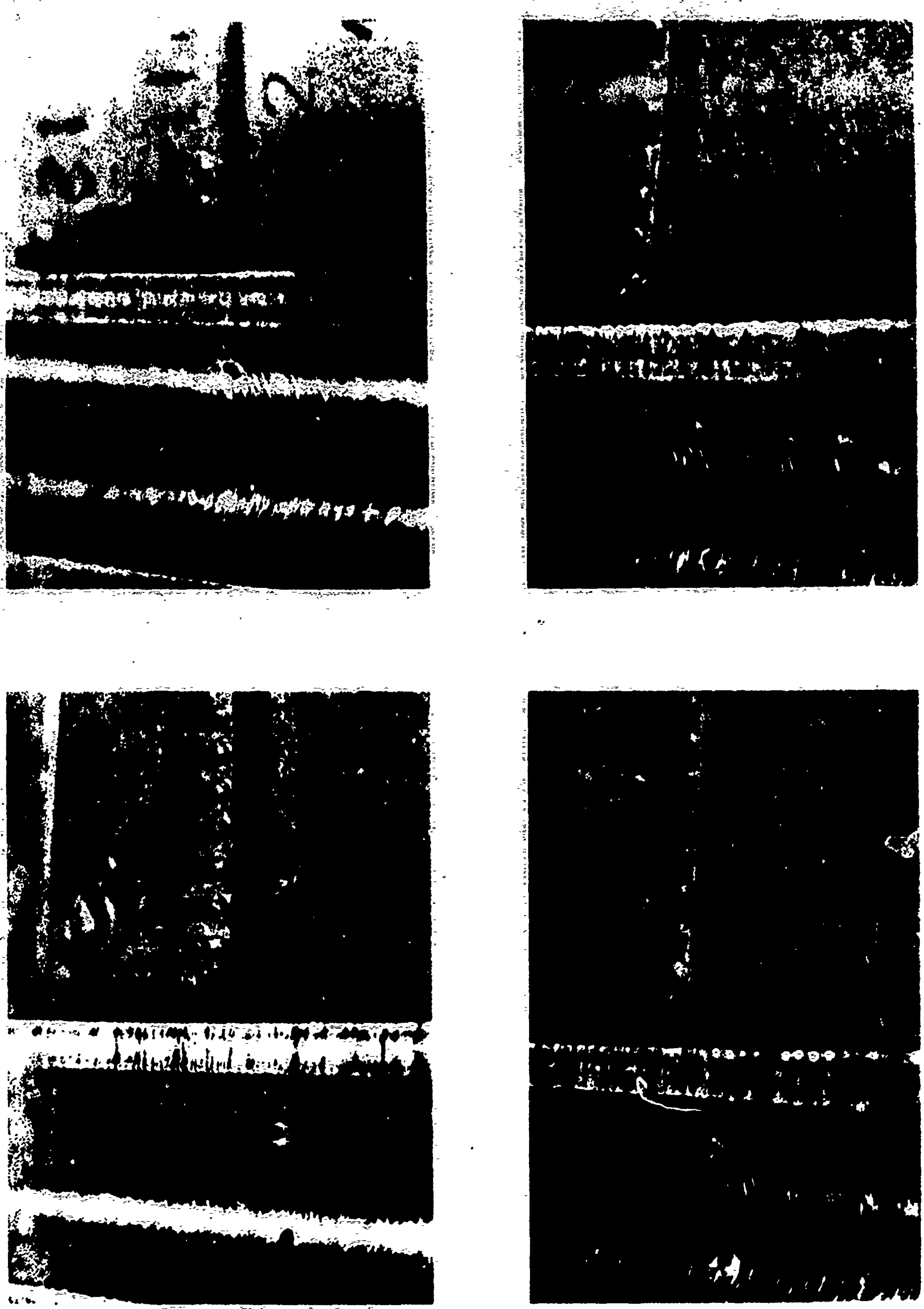


FIGURE 1.3.1.2.2.4

FIGURE 1.3.1.2.2.5

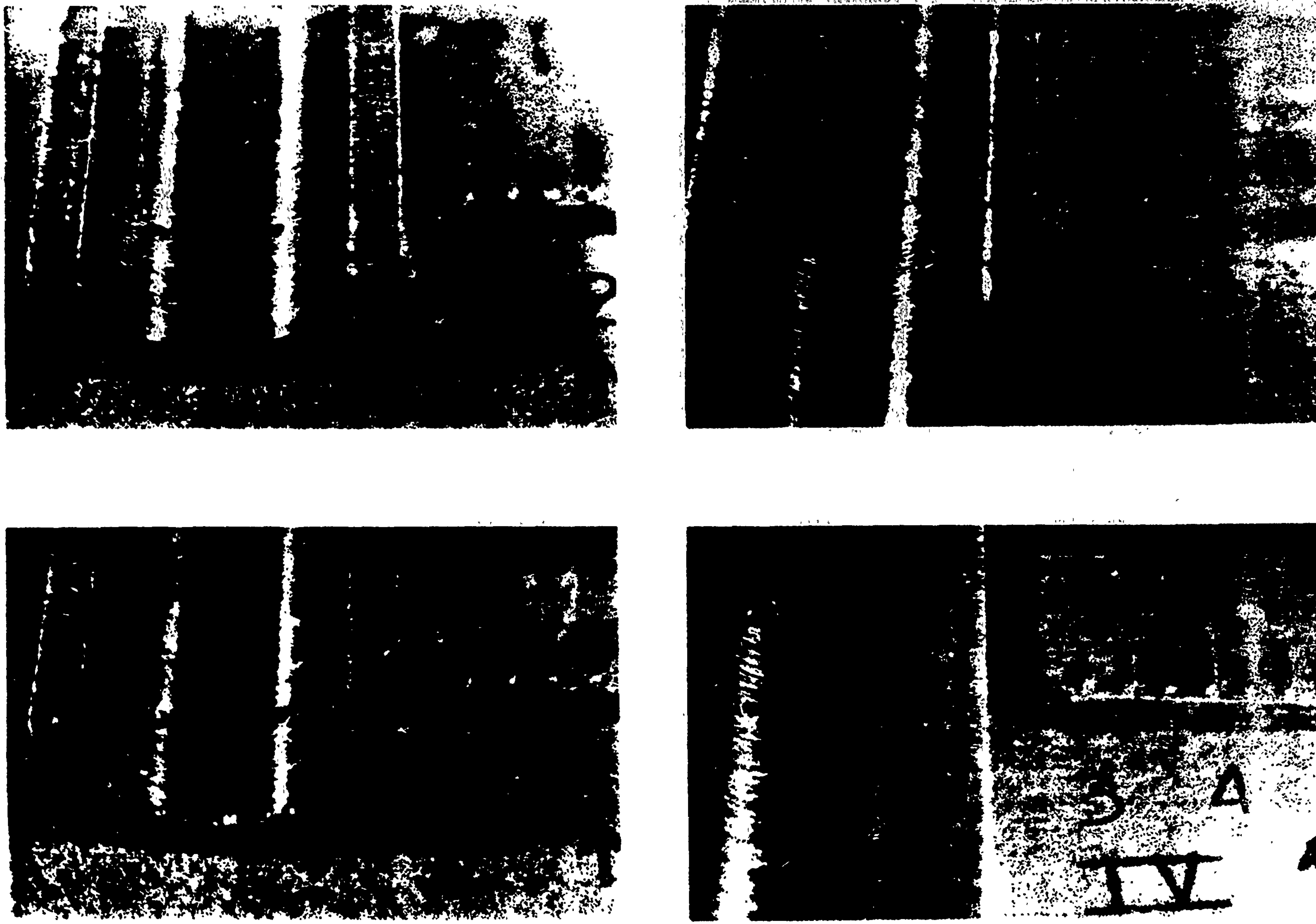
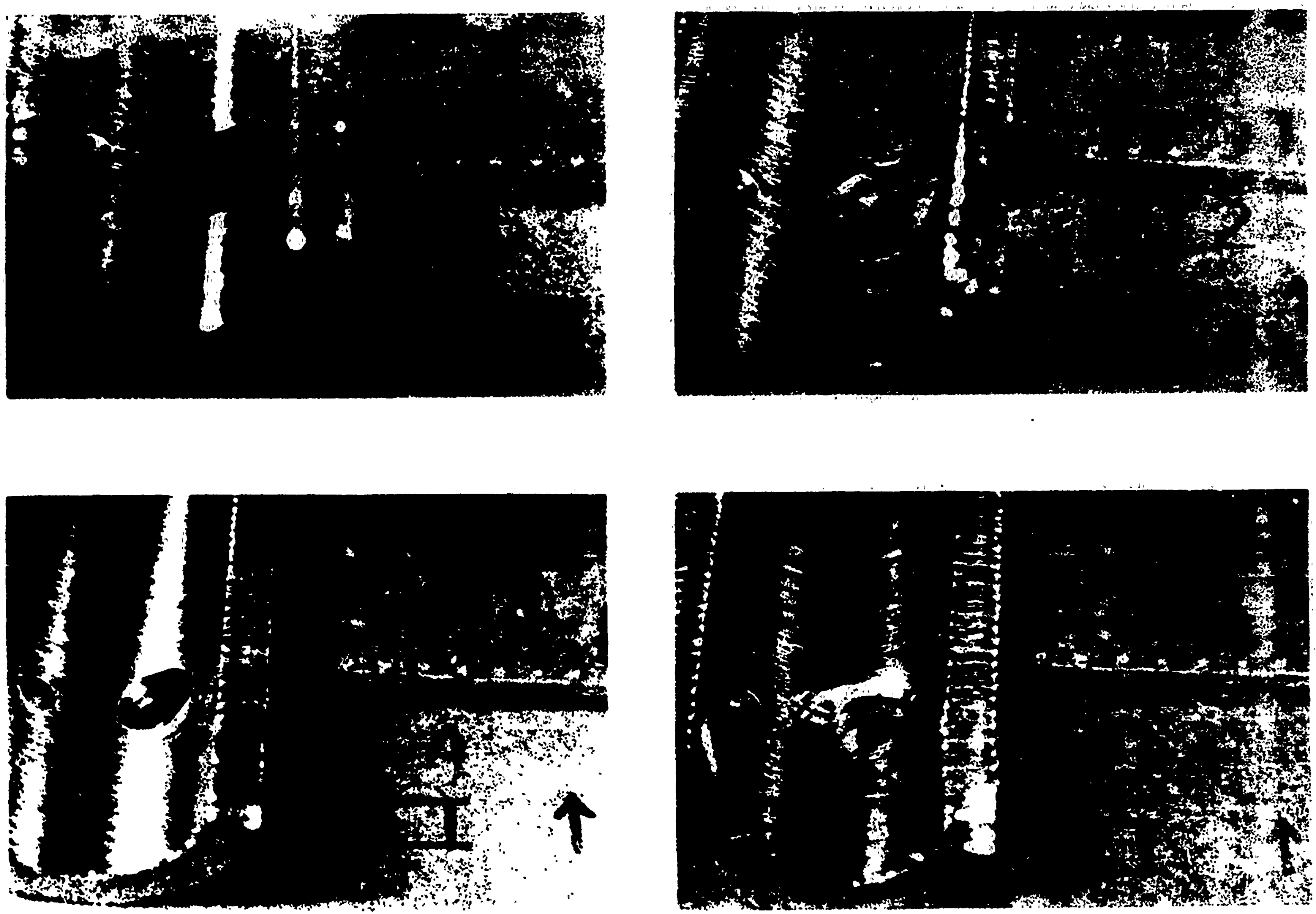


FIGURE 1.3.1.2.2.6



1.3.1.3 Tap Hole Quality Assessments

1.3.1.3.1 Theory

The maximum static pressure error that could exist at any static pressure tap would be that due to the velocity components of the total fluid pressure, since:

$$P_{total} = P_{static} + P_{velocity}$$

therefore:

$$P_{static} = P_{total} + KP_{velocity}$$

where: K = a constant varying from 0 to 1 depending on how much of the velocity component the pressure tap detects. K may be negative due to the fact that the static tap, depending on its shape, may detect either an upstream or downstream velocity component.

The velocity component of total pressure is given by the expression:

$$h = \frac{\rho v^2}{2g}$$

where: h = pressure head (length)
ρ = fluid density (mass/volume)
v = velocity (length/time)
g = acceleration due to gravity.

For a fluid density of 1, the head expressed in units of pounds per inch^2, and velocity in ft/sec, the expression reduces to:

$$PSI = (.00674)(v^2) .$$

This expresses the maximum pressure error that could exist in making a static pressure measurement, because it would require a tap design so grossly in violation of good practice, that the static tap would in fact be a 100% efficient pitot tube, pointed directly up- or downstream.

1.3.1.3.2 Pressure Tap Test Results

Figure 1.3.1.3.1 illustrates the results of Section 1.3.1.2 as compared to the maximum theoretical pressure error that could be obtained due to velocity head.

The worst case of all the taps investigated (Series I, 1-6, 1 1/2" pipe), produced a pressure error (when connected for specific gravity) of 47% of the dynamic head. The worst case of all the improved taps (Series VIII, 1-4, 1 1/2" pipe), produced a pressure error of 12.6% of the dynamic head.

As a rule, the pressure errors increased as a constant percentage of the dynamic head. The exceptions to this were the series of holes in which all the holes were deburred. Apparently, the errors contributed by the reference holes as compared to the test holes then became significant and caused the pressure differential readings to appear erratic.

The largest pressure errors occured where there were large burrs on the upstream side of the pressure tap under test. (1 1/2 inch pipe, Series 1, holes 3 and 6 as examples). These upstream burrs caused the pressure readings to be lower than the reference tap of the same series. Burrs on the downstream side also produced pressure readings lower than the reference taps, but not as large in magnitude. (1 1/2 inch pipe, Series 4, hole 4, and Series 3, hole 3, as examples).

The pressure errors for the 1/2 inch pipe were significantly lower than those for the 1 1/2 inch pipe (5.2 PSI maximum for the 1/2 inch vs 11.25 PSI maximum for the 1 1/2 inch). This could be due to several possibilities, some of which are: 1) the surface finish of the 1 1/2 inch pipe was much rougher than the 1/2 inch pipe (approximately 130 microinches vs 32 microinches). 2) The minimum area/burr height ratio for the 1 1/2 inch pipe was 16 vs a minimum of 21 for the 1/2 inch pipe. 3) The fact that the holes are smaller in diameter may reduce their ability to capture some of the dynamic pressure component.

The improved tap holes that varied in size to reduce the tap hole length/diameter ratio from 2 down to .3 were not nearly as significant in producing pressure errors as the existence of burrs at the tap holes. The worst case was for the 1 1/2 inch pipe, Series 6, holes 1-2, where the 1.3 psi difference was only 4.5% of the dynamic head at 70 ft/sec. (Compared to the 47% for the worst unimproved hole).

1.3.1.3.3 Conclusions

The type of pressure tap hole to be used in making a pressure measurement depends on three things:

1. maximum error contribution by the tap hole that can be tolerated.
2. pressure level (magnitude) to be measured.
3. velocity of the system fluid of which pressure is to be measured.

If, for example, it is desired to make a pressure measurement that is accurate within 1% of reading, the error contributions from several sources must be considered. (Pressure gauge, calibration source, interpolation errors, gauge snubber, tap hole, etc.). We can assign a maximum contributing factor, (1/10 for example) that each of the above sources can add towards the final ± 1% measurement. This means then,

that the maximum error allowed by each source would be 0.1% of reading, and the error contribution (E.C.)of the pressure tap must be no greater than .001.

Using the maximum theoretical pressure error that could exist at a pressure tap due to fluid velocity, it is possible to draw a curve (Figure 1.3.1.2.2.1) of γ fluid velocity vs. minimum pressure reading allowed for an E.C. = .001 since:

$$\text{minimum pressure reading allowed} = \frac{\text{pressure error due to tap}}{\text{error contribution}}$$

An interesting observation can be made from Figure 1.3.1.3.3.1. If, for example, all pressure readings are above 700 psi, and the maximum, fluid velocity never exceeds 10 feet per second, it makes absolutely no difference what the condition of the pressure tap hole is! The maximum error contribution will never exceed .001 as long as the intercept of pressure reading and fluid velocity falls below the curve. This also would mean there would be no need for multiple tap holes. However, the general guidelines set forth for the <u>location</u> of the pressure tap by ISO/TC-131?SC-8 should still be adhered to.

If the intercept falls above the curve several options are open:

1. take readings at a lower velocity point in the system.
2. take readings at a higher pressure.
3. accept a larger error contribution.
4. use a pressure tap with a smaller pressure error (improved tap).

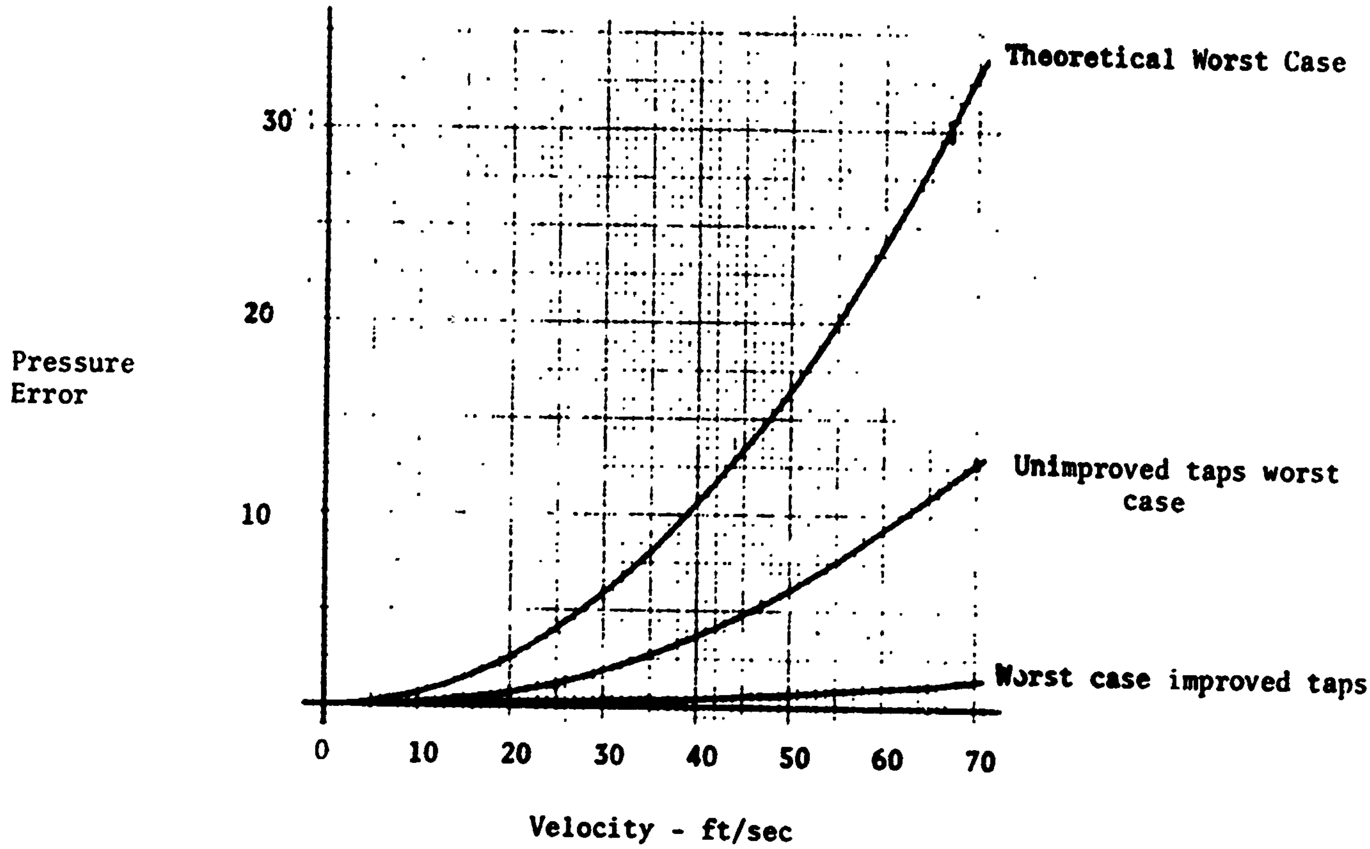
For the purposes of this report, 4 will be investigated.

Figure 1.3.1.3.3.1 shows a "safe" line of operation based on the worst case data obtained from all the improved (deburred) holes. (12.6% of the dynamic head). With this improved pressure tap, it is possible to measure down to 85 psi at the same 10 ft/sec before the error contribution exceeds .001. However, this is being pessimistic since it is the worst case and the average error for all the improved taps is more like 1.25% of the dynamic head. The "safe" line for this average percentage would allow readings down to 8.4 psi at 10 ft/sec before the error contribution of .001 would be exceeded.

But, it would be presumptuous to assume that the average results obtained in this limited test are representative of all situations in fluid power systems.

Therefore, it becomes necessary when high accuracy is required to have a method of qualifying a pressure tap to determine where its "safe" line falls on the velocity vs. minimum pressure reading curve. This could be done by placing 4 holes radially around the pressure line, deburring all the holes, and measuring the differential pressures between them at fluid velocities in the range that the tap will be used, such as outlined in Sections 1.3.1.1 and 1.3.1.2 of this report.

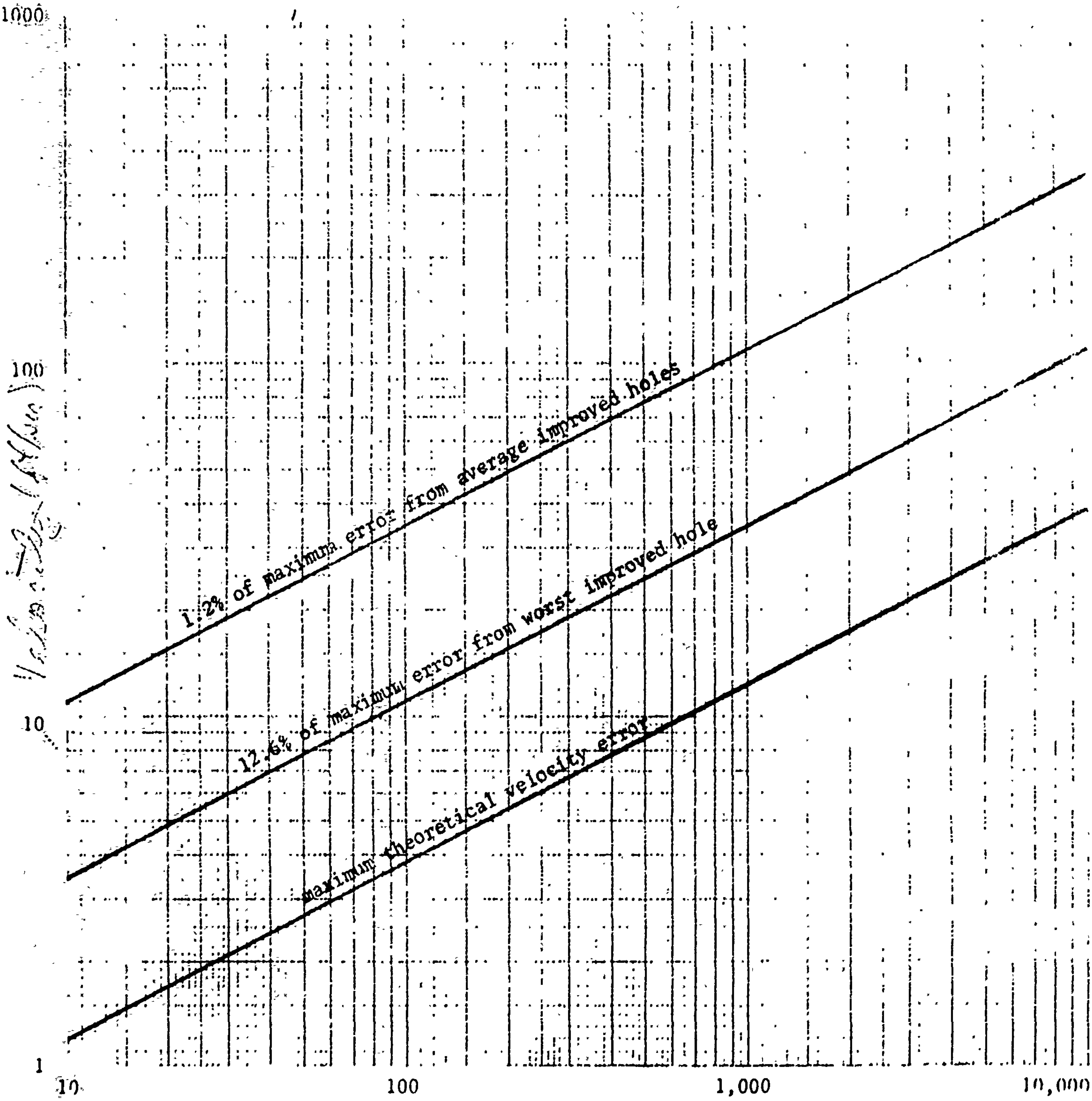
Figure 1.3.1.3.1



The maximum pressure difference between any two holes then becomes the pressure error due to any one of the 4 taps. The minimum pressure that the tap can be used at these specific velocities is then:

$$\text{minimum pressure allowed} = \frac{\text{max. pressure error}}{\text{error contribution}}$$

After the tap is qualified, only <u>one</u> tap hole should be used for the pressure measurements, (not a piezometer ring) since if a pressure difference exists between any two tap holes and they are connected together, a flow will exist from one tap to the other. This raises the real possibility that the pressure errors at each tap could change by an unknown amount because of flow patterns changing at the tap holes and give a combined reading that has more pressure error than each tap alone.



Minimum Allowable Pressure Reading - PSI

FIGURE 1.3.1.3.3.1

Error Contribution = .001

1.3.1.4 Investigation for Ripple Free Supply

Purpose: Investigation of the high flow circuit of the 300 HP stand in the Fluid Power Institute Laboratory to determine the amount of pressure ripple and methods of reducing the pressure ripple for use in the laboratory studies of tap-hole quality.

Procedure: The output of the high flow circuit from the FPI 300HP stand was plumbed as shown in Figure . The precharge on the accumulator was varied from below to above system pressure while the pressure ripple was monitored on the oscilloscope. Pictures of the oscilloscope traces were taken at each accumulator precharge condition.

Results: The accumulator reduced the amount of ripple at the pressure transducer tap location substantially (from 24% with the accumulator effectively removed from the circuit with a 150 psi precharge, to 4% at a precharge of 25 psi).

Test conditions for all oscilloscope traces:

flow rate = 350 gpm

P_1 = 146 psig

P_2 = 100 psig

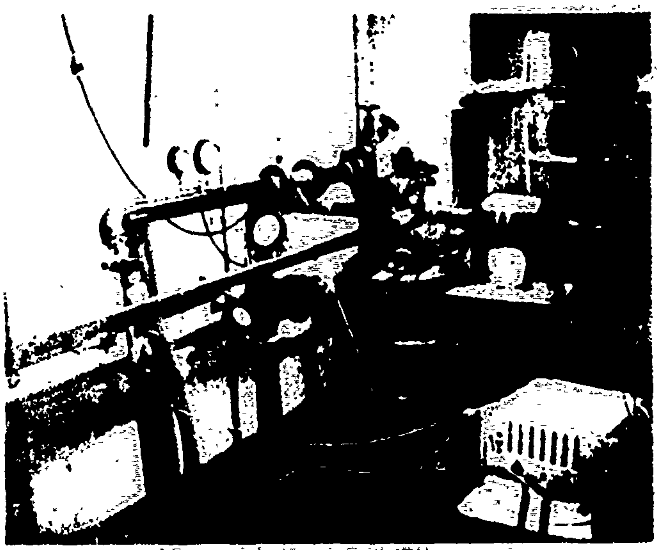
valves 11 and 4 wide open

20 millisec/cm horizontal sweep

20 psi/cm vertical

Note: Oscilloscope in the "AC" mode, therefore, traces indicate only pressure ripple, not pesssure level.

1.3.1.4.1 Preliminary Investigation Set-Up



The high flow supply was plumbed through the wall and directed into the tee containing the accumulator. The flow was directed through the long length of pipe in the foreground and returned by hose through the turbine flowmeter to the reservoir. Pressure was monitored with the transducers connected to the piezometric taps on the long length of pipe. Flow data was read out on the counter in bottom-right corner of picture.

Conclusions

It was felt that the reduction from 24% pressure ripple to a 4% Ripple was enough to eliminate the possibility of cyclic dynamic effect errors at the pressure tap holes. Therefore the relative pressures of the pressure taps due to the velocity effects of the oil passing the pressure tap holes could be investigated independently of other phenomena such as offset errors caused by non-linear snubbers as covered in Section 1.2.1.3.

EQUIPMENT AND INSTRUMENTATION LIST FOR PRELIMINARY INVESTIGATION FOR PRESSURE-RIPPLE-FREE SUPPLY

1. Crosby Bourdon tube pressure gauge for reference. No. 300-2, Range 0-300 psig

2. Marsh Instrument Company 1/4" needle valve used as a pressure snubber. No. 1900 FFG

3. Greer Hydraulics, Incorporated dry nitrogen charged accumulator No. A104-200, MSOE No. 9385

4. Schaible 2" gate valve, Model 125

5. Ashcroft Bourdon tube pressure gauge for reference. Range 0-200 psig

6. Grove 1/4" needle valve used as a pressure snubber, No. 310K

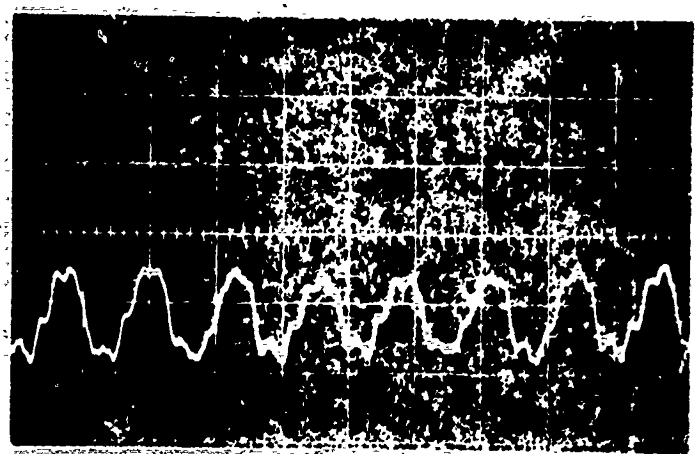
7 & 8. Pace Engineering Company variable reluctance pressure transducers Model P3D;
    Serial No. 17533 with 500 psid plate
    Serial No. 15988 with 100 psid plate
  Two Pace Transducer Indicators, Model CD25
    Serial No. 18922
    Serial No. 16312
  Two Tektronix Type 531 Oscilloscopes with camera attachment

9. A.O. Smith 3" turbine flowmeter with magnetic pickup driving a 6 digit Beckman counter

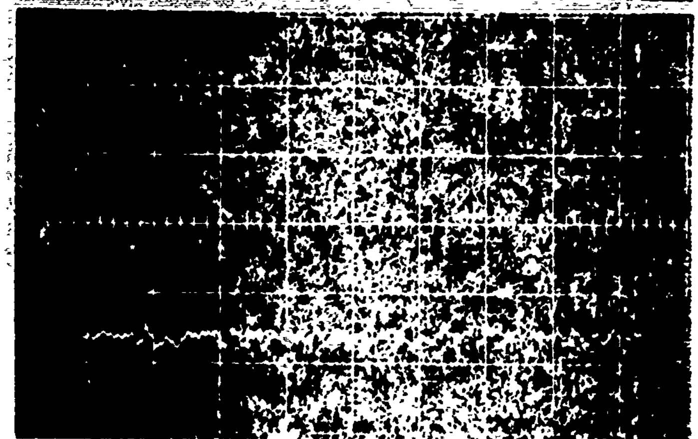
10. Accumulator charge checked with a Crosby Bourdon tube pressure gauge. No. 160-2, Range 0-160 psig

11. Powell 2" gate valve

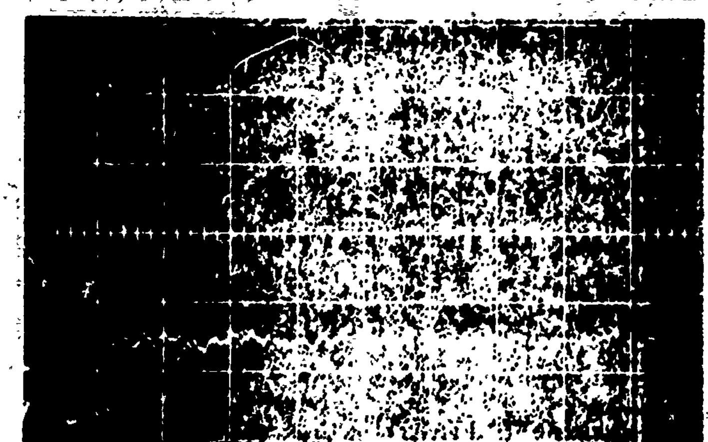
1.3.1.4.2 [illegible]



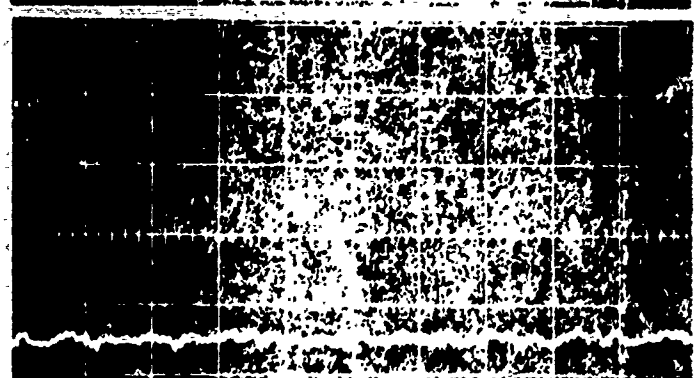
150 psig
Accumulator
Precharge



125 psig
Accumulator
Precharge



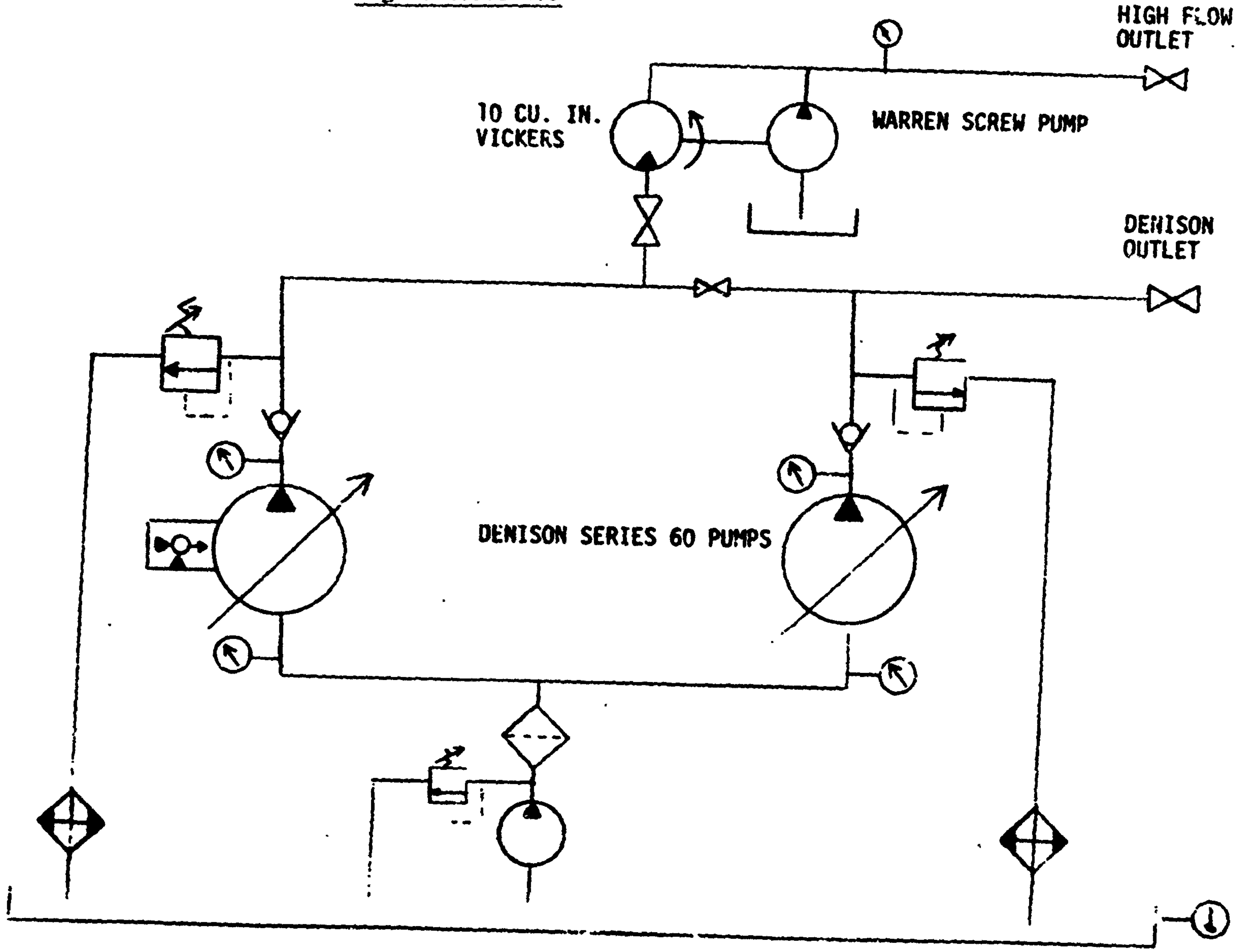
50 psig
Accumulator
Precharge



25 psig
Accumulator
Precharge

FPI HYDRAULIC SCHEMATIC FOR 300 HP TEST SUPPLY

Figure 1.3.1.4.3



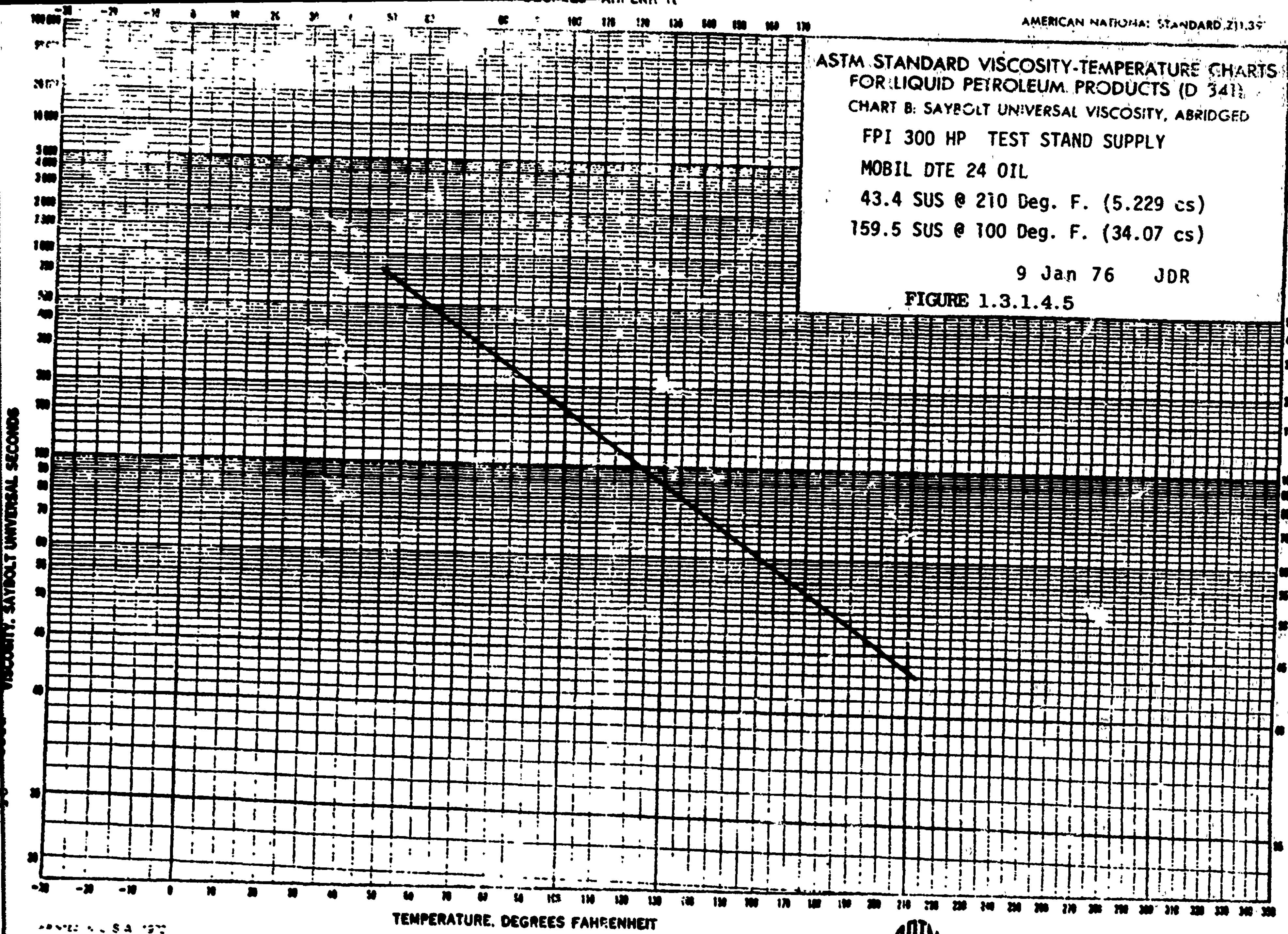
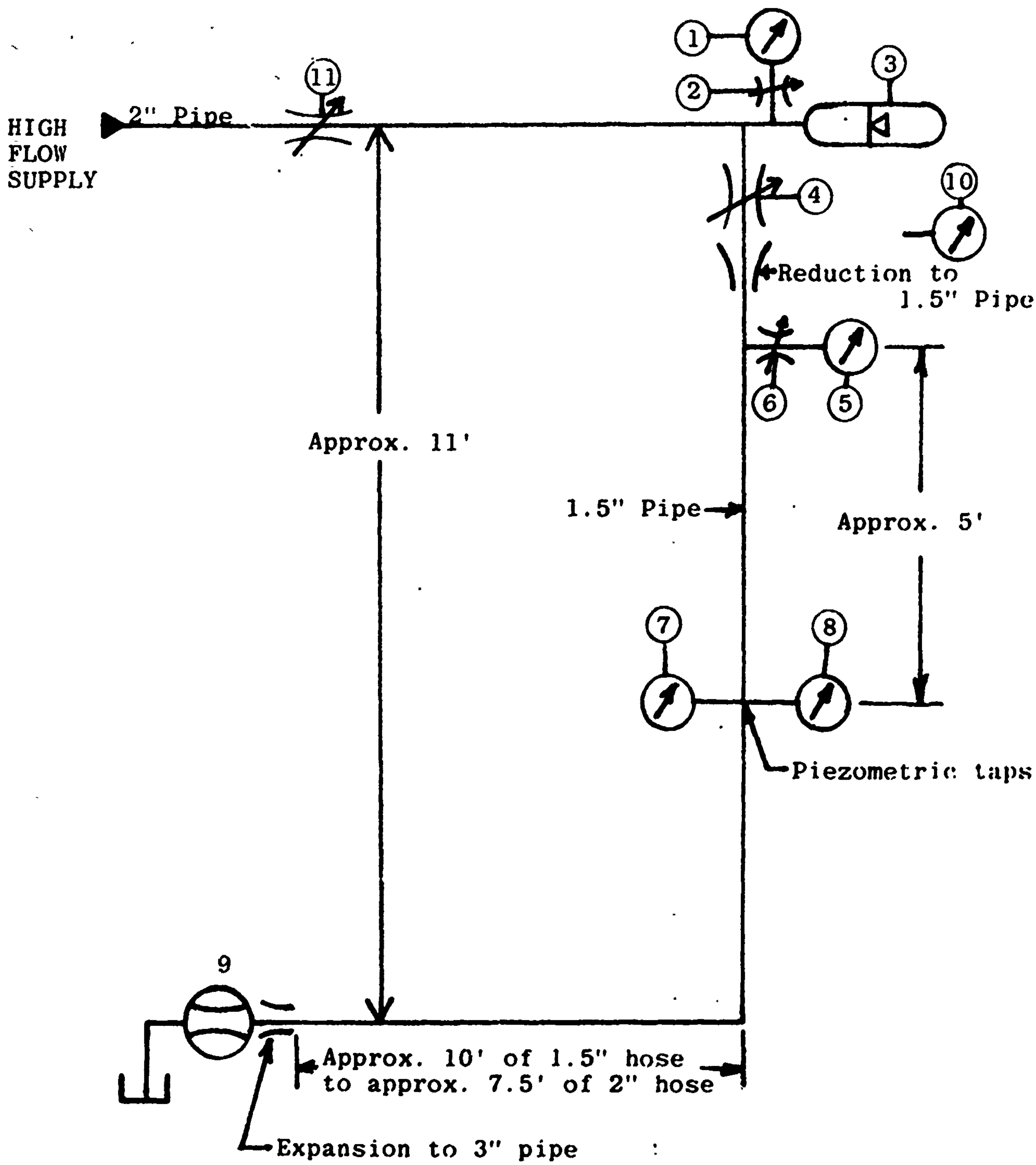


FIGURE 1.3.1.4.5

CIRCUIT SCHEMATIC FOR PRELIMINARY INVESTIGATION

FOR PRESSURE-RIPPLE-FREE SUPPLY

FIGURE 1.3.1.4.4



1.3.2 Tap Hole Quality - Dynamic Considerations

Purpose: To make a cursory estimate of effect of tap hole quality upon the instantaneous indicated pressure in a pulsating pressure system.

Scope: the study was:

a) limited to comparisons of very few holes, and
b) intend to provide only a crude assessment of the effects and not necessarily lead to specific means of dealing with the problems.

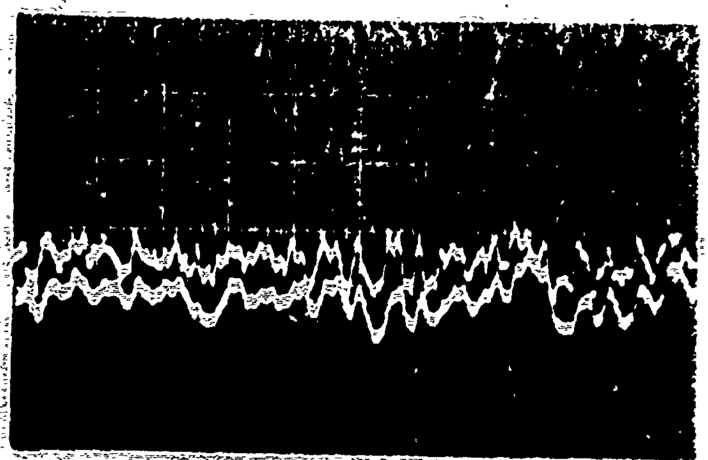
When pressure ripple wave shapes obtained from two pressure taps located radially about the same point in a fluid transmission line are compared on an oscilloscope, it appears that pressure peaks occur at approximately the same point in time for clean holes (see top set of traces in Figure 1.3.2.1). However, when one of the holes being compared has a burr on it, the general wave shape can be significantly affected in terms of peak timing (see second set of traces in Figure 1.3.2.1), and peak amplitude (see third set of traces in Figure 1.3.2.1). Because the waveshapes are significantly different, it must be concluded that the presence of burrs introduces dynamic phenomena in the tap hole that are not borne by the fluid elsewhere. It can probably be explained on the basis that the burr creates its own turbulence which is sensed by the measuring instrument.

It must be further concluded that when the standards writing bodies begin the task of dynamic measurements, the tap hole quality which gives adequate accuracy for average pressure measurement will not suffice for dynamic pressure measurement.

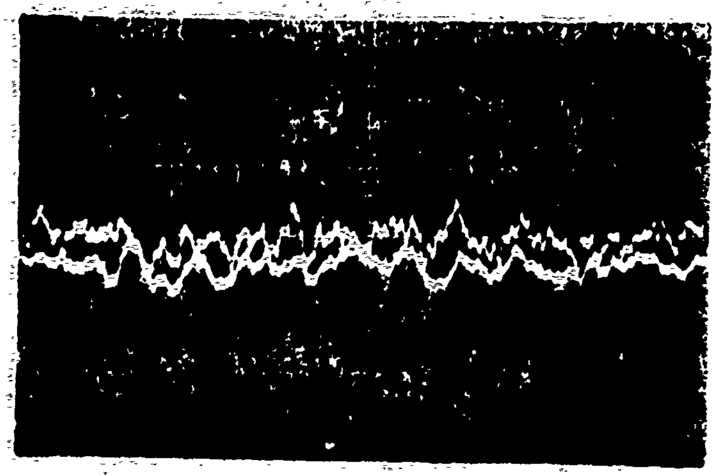
OSCILLOSCOPE TRACES OF PRESSURE RIPPLE IN SERIES ONE OF 1 1/2 INCH PIPE STUDY

FIGURE 1.3.2.1

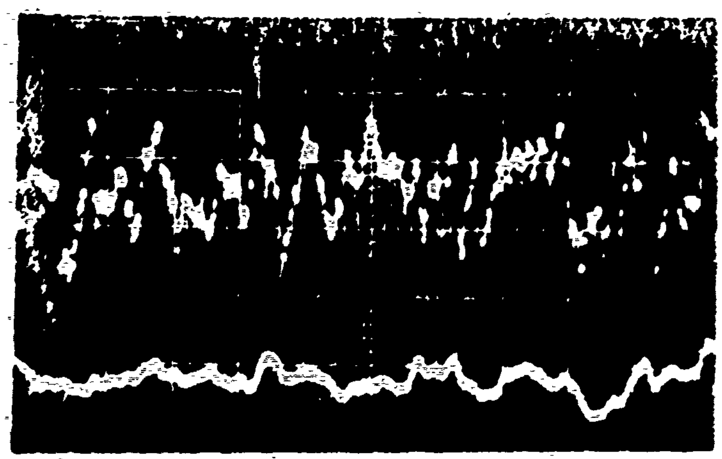
The flow rate was 189 gpm for all three sets of traces. The oscilloscope sweep speed was 100 m sec/cm for all three set of traces. The bottom trace in all three sets of traces was of hole number one (or clean hole) and calibrated to .5 psi/cm vertically.



Top trace is hole number five, which was nearly free of burrs. Vertical calibration arbitrary, showing wave shape only.



Top trace is hole number six, which had a large burr. Vertical calibration arbitrary, showing wave shape only.



Top trace is also hole number six, hoever, it has a vertical calibration of .5 psi/cm.

SECTION 2

A PROPOSED STANDARD METHOD FOR THE MEASUREMENT OF AVERAGE STEADY-STATE STATIC PRESSURE IN A HYDRAULIC FLUID POWER CONDUCTOR

INTRODUCTION TO PART 2

The attached proposed pressure measurement standard has been developed around several subjective assumptions. As a result, the requirements for conformance are very restrictive, perhaps too restrictive, however, decisions to ease those requirements by changing the assumptions can be accomplished most effectively through scrutiny and debate by the world's experts. It is in that spirit that this document is submitted.

The first big assumption is that the Total Error Objectives agree with current proposals at ISO/TC-131/SC-8 which are 0.5%, 1.0%, and 2.5% for the three accuracy classes and that they are indeed desired and needed. Secondly, liberal use has been made of the popular "10-to-1 Rule" requiring, for instance, that the calibrating reference be at least 10 times more accurate than the calibrated instrument. The third assumption is also drawn from the 10-to-1 Rule; of those factors which are known to contribute to the Total Error in a quantifiable way, each one has been forced to contribute no more than 10% to the Total Error. A further assumption is that the Error Contributions are adding linearly, rather than by the square root of the sum of the squares.

The final result is that 80% of the world's present pressure measurement capability may be unqualified if these assumptions indeed prevail after full international debate.

A STANDARD METHOD FOR THE MEASUREMENT OF AVERAGE

STEADY-STATE STATIC PRESSURE IN A HYDRAULIC FLUID POWER LINE

The purpose of this study is

2.1.0 Purpose:

To set forth the procedures and criteria for the acceptably accurate measurement of the true average steady-state static pressure in fluid power systems. The scope

2.2.0 Scope; this standard:

2.2.1 Is limited to the measurement of average steady-state static pressure in closed conductors:

2.2.1.1 which are transmitting hydraulic fluid power.

2.2.1.2 with fluid velocities are less than 25 metre per second.

2.2.1.3 with pressure pulsations with peak-to-peak amplitudes are less than 100% of the average steady-state static pressure.

2.2.1.4 carrying fluids have ~~with~~ specific gravities between 0.6 and 1.2.

2.2.1.5 with average steady-state static pressures are less than 700 bar.

2.2.1.6 which have inside diameters are greater than 3.0 millimetre. Excluded are

2.2.2 Includes three pressure measurement accuracy classes which are expressed in percent of reading, the total error objectives being

Class A ±0.5%
Class B ±1.0%
Class C ±2.5%.

2.2.3 Specifically excludes the criteria for the location of pressure taps upstream and downstream of flow disturbances, such criteria being within the scopes of the specific component or system test procedure standard. Included are

2.2.4 Includes those identifiable effects which contribute significantly to the total error in pressure measurement.

2.3.0 Conformance:

A given pressure measurement shall conform to this standard only if all criteria for a given accuracy class are met.

2.4.0 Definitions

2.4.1 Agency: Any person or organization or part, section, department or division of an organization which maintains equipment and supporting records for the purpose of engaging in any or all of the following:

A. Calibration of Reference Standards
B. Calibration of Working Instruments
C. Testing of Fluid Power Equipment.

2.4.2 Calibration: The process of comparing a first Reference Standard to a second Reference Standard or Working Instrument for the purpose of assessing the accuracy of the Second Reference Standard or Working Instrument.

2.4.3 Certificate: A written statement by a Certified Calibration Agency that a calibration has been carried out in accordance with this standard.

2.4.4 Certified Calibration: The process of comparing a Certified Reference Standard to another Reference Standard or Working Instrument and providing supporting documentation in accordance with this standard.

2.4.5 Certified Calibration Agency: Any Agency which maintains Reference Standards and supporting documentation in accordance with this standard.

2.4.6 Certification Lineage: That path which traces the calibration of an instrument to the Ultimate Reference Standard.

2.4.7 Correction Chart: A chart developed from Calibration data, which when utilized, brings the Indicated Value into closer agreement with the actual value of a pressure.

2.4.8 Dummy Calibration: A process whereby a pressure signal to a transducer is simulated electronically in order to facilitate the return of electronic gains to the levels used during Calibration. Use of Dummy Calibration is not a substitute for Verification.

2.4.9 Error: The uncertainty surrounding a given pressure measurement which establishes the boundries within which the true value lies relative to the Indicated Value.

2.4.10 Error Contribution: An estimate of that amount of uncertainty which contributes to the Total Error and is attributable to a single error producing phenomenon.

2.4.11 Indicated Value: The best estimate of the value of the pressure in a system based upon the human interpretation of a pressure readout device. Synonym: Reading

2.4.12 Instrument: Any device or combination of devices used for the measurement of pressure.

2.4.13 Measurement Situation: That time when a Testing Agency incorporates Working Instruments in the testing of final power components and/or systems.

2.4.14 Minimum Allowable Reading: The minimum Indicated Value which can be read from a particular instrument and which is established in consideration of working Instrument readability and its Calibration repeatability and imposed on the instrument in passuit of an accurate measurement.

2.4.15 Physical Standards Laboratory: That agency which is recognized by a government as capable of maintaining Ultimate Reference Standards.

2.4.16 Pressure Measurement System: All those devices which are interconnected between the system, the pressure of which is to be measured, and the final readout device.

2.4.17 Pressure Ratio: A term applied to the ratio of average pressure to peak-to-peak pulsations and is used in assessing the applicability of a particular snubber in a given Measurement Situation.

2.4.18 Pressure Transducer: Any device which senses fluid pressure and converts it to another physical quantity, such as voltage, current, frequency, velocity, etc.

2.4.19 Readout Device: That mechanism which connects to a transducer or transducer interface and which ultimately displays the pressure within a system in a human interpretable form. It may produce analog (deflection) or digital data.

2.4.20 Reference Standard: A pressure measuring device or combination of devices and/or a pressure source which is/are used to calibrate other pressure measuring devices and/or sources.

2.4.21 Reference Standard, Intermediate: A Reference Standard maintained by any person or organization other than the Physical Standards Laboratory and which has been certified in accordance with this standard.

2.4.22 Reference Standard, Laboratory: A Reference Standard which is permitted between the Ultimate and/or Intermediate References in certain special cases, criteria for which are contained in this standard.

2.4.23 Reference Standard, Ultimate: That Reference Standard maintained by the Physical Standards Laboratory. The most authoritative Reference Standard in a given country.

2.4.24 Snubber: A hydraulic restriction deliberately placed between the source of pressure to be measured and the pressure transducer for the purpose of damping pressure pulsations and thus to facilitate the observation of true average static pressure.

2.4.25 Static Pressure: That pressure in a line which does not include effects due to fluid momentum. That pressure, the accurate measure of which is being sought as a result of conformance with this standard.

2.4.26 Steady-State: An operating condition in a hydraulic system which is characterized by the fact that

and where and are arbitrary and is an interger multiple of the period of the fundamental frequency of the pressure pulsation.

2.4.27 Symmetry Test: A test conducted on a Snubber for the purpose of determining the extent to which its reverse pressure-flow characteristic agrees with its forward pressure-flow characteristic for the further purpose of assessing its Error Contribution.

2.4.28 Testing Agency: Any Agency which conducts tests on Fluid Power Equipment.

2.4.29 Total Error: The total uncertainty in the value of a measured quantity caused by the total effect of all Error Contributing phenomena, attributable or not.

2.4.30 Total Error Objective: That amount of uncertainty in a given pressure measurement which is sought as a result of compliance with this standard. There are three objectives:

Class A 0.5% of Indicated Value
Class B 1.0% of Indicated Value
Class C 2.5% of Indicated Value

2.4.31 Transducer, Pressure: Any device which converts pressure to another physically measurable observable quantity, such as motion, voltage, frequency, etc.

2.4.32 True Reference Value: The best estimate of the actual pressure experienced by an instrument during its calibration, taking into account corrections in fluid column height and calibration corrections for the Reference Standard. It should not be confused with the true value of the pressure, which can never be known exactly.

2.4.33 Verification: A procedure applied to Working Instruments dissimilar to Calibration only in the amount of data taken, the frequency of use and the Certificate is not re-issued, it is instead annotated.

2.4.34 Working Instrument: A pressure transducing device, which includes interconnecting linkages, any necessary signal conditioning and signal processing and the readout device, which is used by the Testing Agency while conducting tests on Fluid Power Equipment.

2.5.0 Requirements of the Reference Standard

2.5.1 A Certified Calibration Agency shall maintain certain Reference Standards, the Certification for which shall conform to the Calibration Lineages shown in Figure 2.5.1.

2.5.2 A Certified Reference Standard shall be used for no purpose other than the Calibration of Working Instruments or other Reference Standards. Use for any other purpose shall constitute immediate cause for re-certification before its next use.

2.5.3 The frequency of re-certification varies with the particular Reference Standard and the desired accuracy class. Re-Certification shall be carried out in accordance Table 2.5.1.

2.5.4 The Reference Standard shall be free of any evidence of abuse, misuse, or damage. Presence of such evidence shall constitute immediate cause for re-certification.

2.5.5 Logs shall be maintained for each Reference Standard to indicate the date of each use, the technician in charge, and the purpose of each use. Failure to comply shall constitute immediate cause for re-certification.

2.5.6 Calibration of the Reference Standard

2.5.6.1 As a convenience, the term "Uncertified Standard" refers to the Reference Standard being calibrated while the term Certified Standard refers to the Reference Standard used for Calibration even though in the strictest technical sense, the Certification may still be valid on the "Uncertified" Instrument.

2.5.6.2 The term True Reference Value shall refer to the best estimate of the actual pressure experienced by the Uncertified Reference Standard and as verified by the Certified Standard plus certain corrections. The True Reference Value is determined by utilizing the correction values or correction chart as reported on the Certificate for the Certified Reference Standard plus the correction for the fluid column height caused by the difference in elevation between the Certified and Uncertified Standards. The formula is True Reference Value = (Correction Allowed on the Certificate of the Certified Reference Standard at the Indicated Value) + $\rho h \times 10^{-5}$, where ρ is the fluid density, as verified by the fluid manufacturer, in newton/cm^3 and h is the height that the Reference Standard is above the Working Instrument in cm. All readings shall be taken in a manner which takes advantage of the parallax error minimizing features. The Uncertified Reference Standard shall be free of any evidence of misuse, abuse, or damage. Such evidence shall constitute immediate cause for re-certification.

2.5.6.3 Set up the Certified Reference Standard in accordance with its Certificate and the recommendation of the manufacturer. If they contain conflicting requirements, the Certificate shall have authority.

2.5.6.4 Connect the Uncertified Reference Standard to the Certified Reference Standard, observing mounting and installation requirements as given by the manufacturer of the Uncertified Reference Standard. Any deviations shall be noted on the Certificate.

2.5.6.5 If the Certified Reference Standard does not contain a hydraulic source, connect a source which has capacity and controllability commensurate with the Uncertified Instrument.

2.5.6.6 Take the necessary precautions to protect personnel and equipment.

2.5.6.7 Set the source pressure to zero (gauge) and assure that both the Certified and Uncertified Standards experience zero (gauge) pressure by disconnecting a common interconnecting line. If the Uncertified Instrument is equipped with separate zero and span adjustments, adjust the Readout Device to indicate zero. Close any open lines.

2.5.6.8 Gradually increase the pressure until the True Reference Value reaches a convenient level near the full scale value of the Uncertified Instrument. That value shall:

2.5.6.8.1 be within 10% of full scale on the Uncertified Instrument.

2.5.6.8.2 correspond to a readily discernible scale mark on an analog Readout Device or a discreet digital value on a digital Readout Device.

2.5.6.8.3 be verified by reading the Certified Reference Standard.

2.5.6.8.4 take into account the corrections allowed in other parts of clause 2.5.6.

2.5.6.9 After increasing the pressure in 2.5.6.8, allow the pressure to stabilize to steady-state and carry out 2.5.6.9.1, 2.5.6.9.2, or 2.5.6.9.3.

2.5.6.9.1 If it is so equipped, adjust the span (gain) on the Uncertified Instrument so that its Indicated Value agrees with the True Reference Value. Repeat steps 2.5.6.7 through 2.5.6.9.1 until there is no readjustment needed for both zero and the Indicated True Reference Value. Proceed to step 2.5.6.10.

2.5.6.9.2 If the Uncertified Instrument is equipped only with a zero adjustment, use it to adjust the Indicated Value to agree with the True Reference Value, if necessary. Readjust the pressure to zero as in 2.5.6.7 and note on the records the amount of deviation from indicated zero on the Working Instrument.

2.5.6.9.3 If the Working Instrument has neither a zero nor span adjustment, proceed with Step 2.5.6.10.

2.5.6.10 Calibrate the Working Instrument by applying True Reference Pressures in accordance with the "Number at Calibration Points" and "Number of Trials" as given in Table 2.5.1.

2.5.6.10.1 Record the data required on Chart 2.7.4.8. However, if the span and/or zero adjustments carried out in 2.5.6.9. produce Indicated Values on the Uncertified Instrument which are in physical units other than those of the Certified Reference Standard, eg, cm, mm, volts, millivolts, milliamperes, etc., convert the readings from the Certified Reference Standard to agree in physical units with the Uncertified Instrument, by multiplying by a factor determined during Step 2.5.6.8. Multiply each True Reference Value by

$$\frac{\text{Working Instrument Indicated Value (2.5.6.8)}}{\text{True Reference Value (2.5.6.8)}}$$

Record these values in the appropriate column in Chart 2.7.4.8).

2.5.6.10.2 Determine the spread by calculating the difference between the maximum and minimum Indicated Values for all trials for a given True Reference Value.

2.5.6.10.3 Calculate the Average Indicated Value by finding the average of all trials.

2.5.6.10.4 Calculate the spread ratio by dividing the spread by the Average Indicated Value.

2.5.6.10.5 The Minimum Allowable Reading (MAR) is the largest value found in applying the formula:

$$\text{MAR} = \frac{\text{spread}/2.0}{\text{EC}(A/B/C)}$$

to each row in Chart 2.7.4.8, where EC is the Error Contribution due to non-repeatability of the Uncertified Instrument and has a value based upon accuracy class as given in Table 2.5.1 commensurate with the type of Reference Standard undergoing Certification.

2.5.6.10.6 Calculate the Deviation for each Trial and each True Reference Value by subtracting each Indicated Value from its corresponding True Reference Value.

2.5.6.10.7 Enter the Maximum Deviation over all trials and given the True Reference Value in the appropriate column.

2.5.6.19.8 Calculate and record the Average Deviation in the appropriate column.

2.5.6.10.9 The Certifying Calibration Agency shall supply correction values which can be applied to each Indicated Value for the Reference Standard being Certified. The correction value is the same as the Average Deviation. Use of the Reference Standard being Certified requires the application of the correction values at each of its Indicated Values. Enter Correction Values in the appropriate column in Chart 2.7.4.8.

CERTIFICATION LINEAGES FOR PRESSURE MEAUSREMENT SITUATIONS

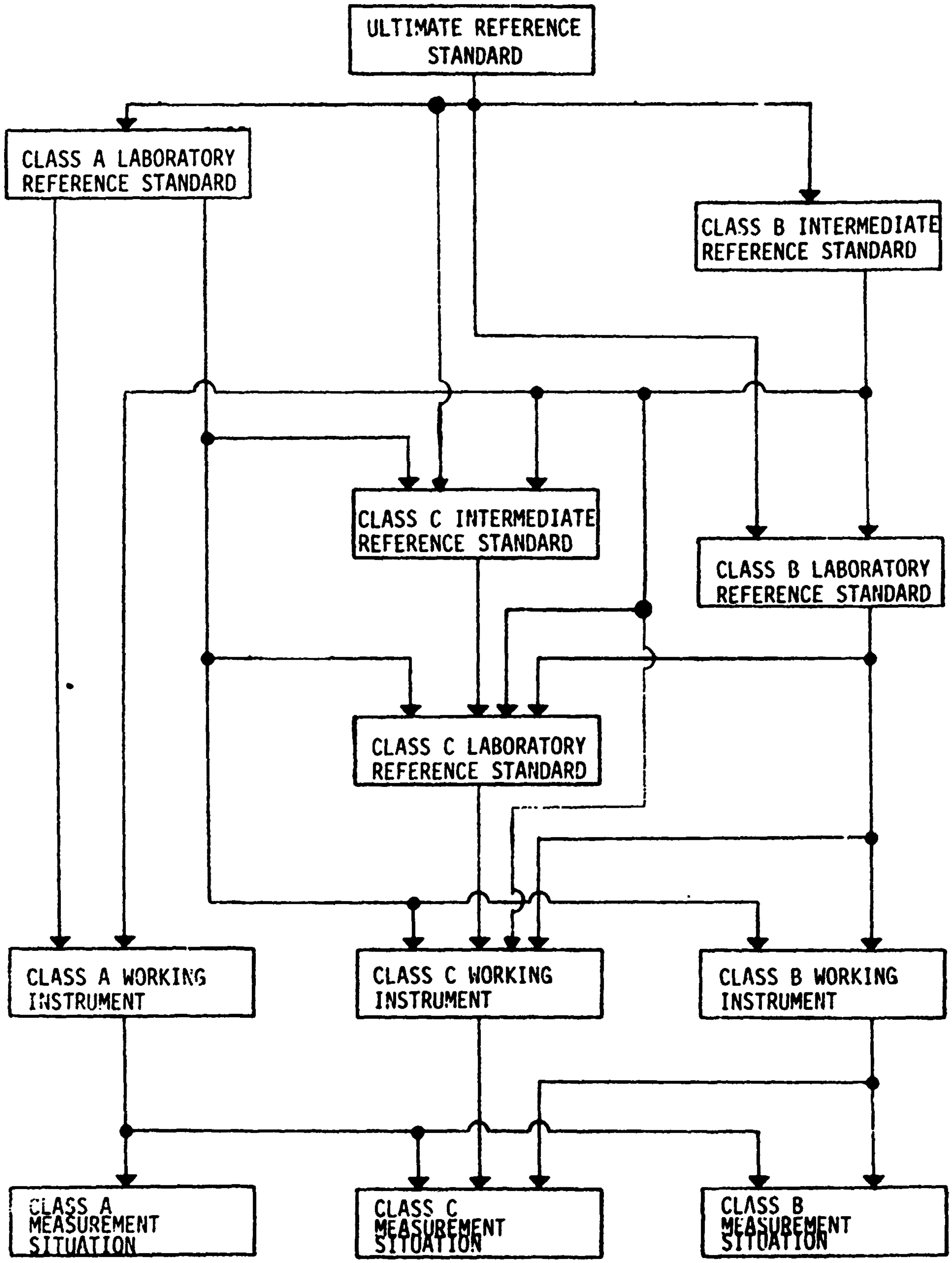


FIGURE 2.5.1

TABLE 2.5.1 CERTIFICATION AND VERIFICATION DATA

		CERTIFICATION AND RE-CERTIFICATION				VERIFICATION			
CLASS	INSTRUMENT	FREQ*	NO. OF TRIALS	NO. OF CALIBRATION POINTS	MAXIMUM ALLOWABLE SPREAD RATIO	FREQ*	NO. OF TRIALS	NO. OF CALIBRATION POINTS	MAXIMUM ALLOWABLE DEVIATION
A	INTERMEDIATE REFERENCE	NOT ALLOWED	--	--	--	--	--	--	--
A	LABORATORY REFERENCE	2 Years	5	10	0.005% of MAR	N/A	--	--	--
A	WORKING INSTRUMENT	2 Mos.	3	10	0.05% OF MAR	EACH USE	1	MAR & FS	0.05% OF MAR
B	INTERMEDIATE REFERENCE	1 Year	7	10	0.001% OF MAR	N/A	--	--	--
B	LABORATORY REFERENCE	5 Years	5	10	0.01%	N/A	--	--	--
B	WORKING INSTRUMENT	6 Mos	3	10	0.1% OF MAR	1 Mo.	1	MAR & FS	0.1% OF MAR
C	INTERMEDIATE REFERENCE	5 Years	3	10	0.01% OF MAR	N/A	--	--	--
C	LABORATORY REFERENCE	5 Years	3	10	0.1% OF MAR	N/A	--	--	--
C	WORKING INSTRUMENT	1 Year	3	10	0.5% OF MAR	6 Mos.	1	MAR & FS	0.5% OF MAR

* Frequency shall be as given, except that evidence of misuse or damage shall be cause for re-certification before the isntrument can be used again.

CODE:
CCA - Certified Calibration Agency
FS - Full Scale
MAR - Minimum Allowable Reading
PSL - Physical Standards Laboratory

2.6.0 Requirements of Readout Devices

2.6.1 Readability of Analog Readout Devices

2.6.1.1 The Readout Device shall be equipped with a parallax error minimizing feature.

2.6.1.2 For a given measurement accuracy class, a given Analog Readout Device shall never be used to read Indicated Values which lie below the Minimum Allowable Reading (MAR), which is calculated from the formula:

$$MAR = \frac{\text{Value of Smallest Scale Division}}{[(RF_1 - 2.0) \times RF_2 + 2.0)] \times EC(A/B/C)} .$$

where EC is the Error Contribution due to readability, and RF_1 and RF_2 are determined from properties of the Readout Device.

2.6.1.2.1 Determine within 10%, the width of the smallest scale division in mm by measuring the total length of the instrument scale and dividing it by the total number of scale divisions. Use this value to enter Figure 2.6.1.2.1 and find RF_1.

2.6.1.2.2 Estimate the width of the pointer to the nearest 0.25 mm in the region on the pointer where the reading is interpreted. Divide the width of the smallest scale division found in 2.6.1.2.1 by the pointer width to form the ratio, α. Use this value to enter the graph of Figure 2.6.1.2.2 and find the value for RF_2.

2.6.1.2.3 Select the accuracy class required and use the appropriate Error Contribution:

EC(A) = 0.0005
EC(B) = 0.001
EC(C) = 0.0025

2.6.1.2.4 Calculate the value of the Minimum Allowable Reading using the formula of 2.6.1.2 and use the Readout Device for Indicated Values above the MAR.

2.6.2 Readability of Digital Readout Devices

2.6.2.1 For a given measurement accuracy class, a given Digital Readout Device shall never be used to read Indicated Values which lie below the Minimum Alloyable Reading (MAR) which is calculated from the formula:

$$MAR = \frac{\text{Smallest Change in the Least Significant Digit}}{EC(A/B/C)} .$$

2.6.2.1.1 Take into account the fact that by design, the least significant digit in some Digital Readout Devices does not have 10 discreet integer levels. Use the value of the smallest integer change possible for the particular readout for use in the numerator of the MAR formula.

2.6.2.1.2 Any feature, automatically or manually deployed, which changes decimal point location is expressly permitted to allow for a reduction in the Minimum Allowable Reading, however, for some accuracy classes, these may be ranges of Indicated Values which are below the Minimum Allowable Reading and yet are above the level which will permit a change in decimal point location. These ranges, if they exist, are expressly outside the particular accuracy class and shall be avoided in conformance with this standard.

2.6.2.1.3 Select the accuracy class required and use the appropriate Error Contribution:

EC(A) = 0.0005
EC(B) = 0.001
EC(C) = 0.0025

2.6.2.1.4 Calculate the Minimum Allowable Reading for each decimal point location using the formula in 2.6.2.1. All Indicated Values shall be above the Minimum Allowable Reading.

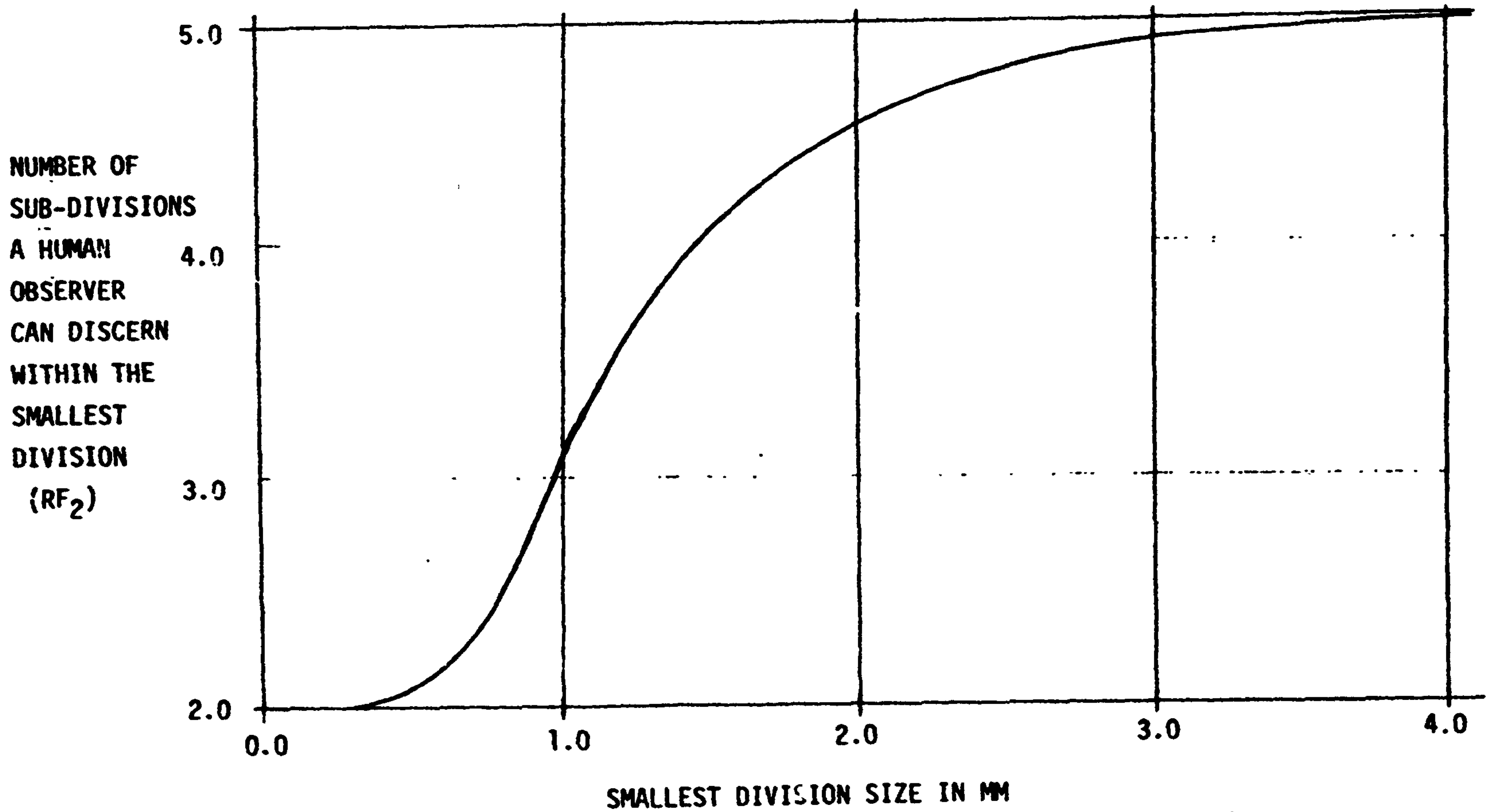
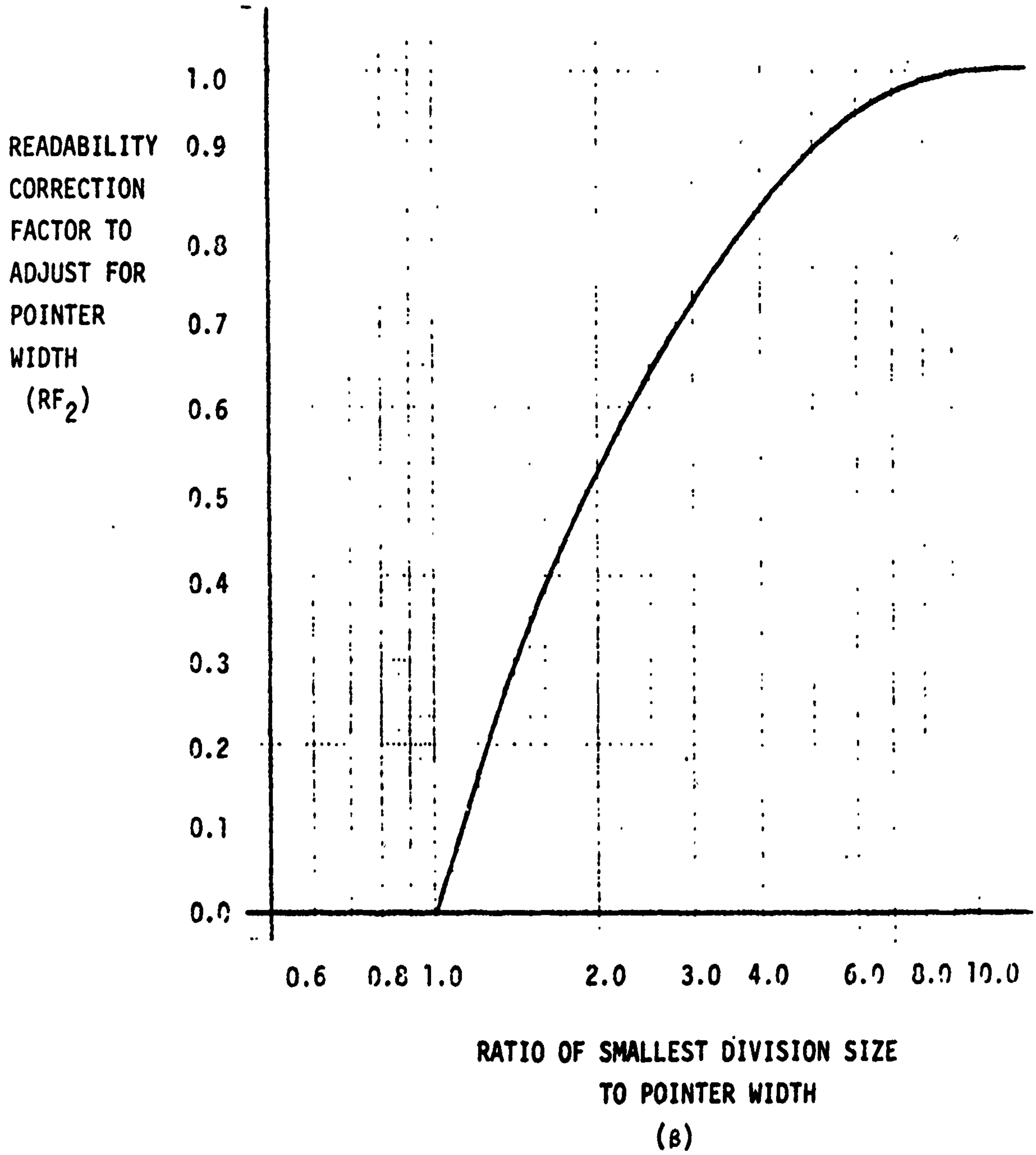


FIGURE 2.6.1.2.1 DIVISION SIZE CORRECTION



<u>FIGURE 2.6.1.2.2 POINTER WIDTH CORRECTION</u>

2.7.0 Requirements of the Working Instrument

2.7.1 The True Reference Value shall be interpreted to mean the best estimate of the actual value of pressure experienced by the Working Instrument and as verified by the Reference Standard. It is determined by utilizing the Correction Values and/or Correction Charts on the Certificate for the Reference Standard, plus the correction for the fluid column height caused by different elevations of the Reference Standard and Working Instrument. The formula is:

True Reference Value = (Correction allowed on the Reference Standard Certificate at that Indicated Value)+ $\rho h \times 10^{-5}$

where ρ is the fluid density in newton/cm^3 and h is the height that the Reference Standard is above the Working Instrument in cm. The Certification Lineage of the Reference Standard shall conform to the requirements of Figure 2.5.1 and its Certification shall conform to the requirements of Table 2.5.1 commensurate with the accuracy class intended for the Working Instrument in the Measurement Situation.

2.7.2 All readings from both the Reference Standard and the Working Instrument shall be taken in a manner which takes advantage of the parallax error minimizing features.

2.7.3 The Working Instrument shall be free of any evidence of misuse, abuse or damage. Such evidence shall constitute immediate cause for re-certification.

2.7.4 Calibration of the Working Instrument

2.7.4.1 Set up the Reference Standard in accordance with its Certificate and the recommendations of the manufacturer. If they contain conflicting requirements, the Certificate shall have authority. The ambient temperature shall agree with the Certification temperature within $\pm$ 5°C.

2.7.4.2 Connect the Working Instrument to the Reference Standard, observing mounting and installation requirements as given by the manufacturer of the Working Instrument. Any deviations shall be noted on the Certificate for the Working Instrument.

2.7.4.3 If the Reference Standard does not contain a hydraulic source, connect a source which has capacity and controllability commensurate with the Working Instrument.

2.7.4.4 Take the necessary precautions to protect personnel and equipment.

2.7.4.5 Set the source pressure to zero (gauge) and assure that both the Reference Standard and the Working Instrument experience zero (gauge) pressure by disconnecting a common interconnecting line. If the Working Ihstrument is equipped with separate zero and span adjustments, adjust the Readout Device to indicate zero. Close any open lines.

2.7.4.6 Gradually, increase the pressure until the True Reference Value reaches a convenient level near the full scale value of the Working Instrument.

2.7.4.6.1 That Value shall: be within 10% of full scale on the Working Instrument.

2.7.4.6.2 correspond to a readily discernible scale mark on an analog Readout Device or a discreet digital value on a digital Readout Device.

2.7.4.6.3 be verified by reading the Reference Standard.

2.7.4.6.4 take into account the corrections allowed in other parts of Clause 2.7.4.

2.7.4.7 After increasing the pressure in 2.7.4.6, allow the pressure to stabilize to steady-state and carry out either 2.7.4.7.1, 2.7.4.7.2, or 2.7.4.7.3. If this is a Verification, proceed to Step 2.7.4.8.

2.7.4.7.1 If it is so equipped, adjust the span (gain) on the Working Instrument so that its Indicated Value agrees with the True Reference Value. Repeat steps 2.7.4.5 through 2.7.4.7.1 until there is no readjustment needed for both zero and the Indicated True Reference Value. Procced to Step 2.7.4.8.

2.7.4.7.2 If the Working Instrument is equipped only with a zero adjustment, use it to adjust the Indicated Value to agree with the True Reference Value, if necessary. Readjust the pressure to zero as in 2.7.4.5 and note on the records the amount of deviation from indicated zero on the Working Instrument.

2.7.4.7.3 If the Working Instrument has neither a zero nor span adjustment, proceed with Step 2.7.4.8.

2.7.4.8 Calibrate the Working Instrument by applying True Reference Pressures in accordance with the "Number of Calibration Points" and "Number of Trials" as given in Table 2.5.1.

2.7.4.8.1 Record the data required on Chart 2.7.4.8. However, if the span and/or zero adjustments carried out in 2.7.4.7 produce Indicated Values on the Working Instrument which are in physical units other than those of the Reference Standard, eg, cm, mm, volts, millivolts, milliamperes, etc., convert the readings from the Reference Standard to agree in physical units with the Working

Instrument by multiplying by a factor determined during Step 2.7.4.6. Multiply each True Reference Value by:

$$\frac{\text{Working Instrument Indicated Value (2.7.4.6)}}{\text{True Reference Value (2.7.4.6)}} .$$

Record these values in the appropriate column in Chart 2.7.4.8.

2.7.4.8.2 Determine the spread by calculating the difference between the maximum and minimum Indicated Values for all trials for a given True Reference Value.

2.7.4.8.3 Calculate the Average Indicated Value by finding the average of all trials.

2.7.4.8.4 Calculate the spread ratio by dividing the spread by the Average Indicated Value.

2.7.4.8.5 The Minimum Allowable Reading (MAR) is the largest value found in applying the formula:

$$\text{MAR} = \frac{\text{spread}/2.0}{\text{EC}(\text{A/B/C})}$$

to each row in Chart 2.7.4.8, where EC is the Error Contribution due to non-repeatability of the Working Instrument and has a value based upon accuracy class:

EC(A) = 0.0005
EC(B) = 0.001
EC(C) = 0.0025 .

This value of Minimum Allowable Reading shall be applicable only when each reading in the Measurement Situation is corrected in accordance with the procedures specified in Step 2.7.4.8.9.

2.7.4.8.6 Calculate the Deviation for each Trial and each True Reference Value by subtracting each Indicated Value from its corresponding True Reference Value.

2.7.4.8.7 Enter the Maximum Deviation over all trials and given True Reference Value in the appropriate column.

2.7.4.8.8 Calculate and record the Average Deviation in the appropriate column.

2.7.4.8.9 The Testing Agency may, at its option, elect to correct the data collected from the Certified Working Instrument during the Measurement Situation, such corrections being derived from the data collected during Calibration of the Working Instrument. The correction process consists of adding the Correction Value to the Indicated Value off the Working Instrument. The Correction Value is found by linear interpolation from a Correction Chart constructed as shown in Figure 2.7.4.8.9.1. It consists of a graph of Average Deviation vs. Average Indicated Value.

CHART 2.7.4.8

CERTIFICATE OF CALIBRATION

DATE________

CERTIFICATE NUMBER____________________

CALIBRATION AGENCY____________________

EXPIRATION DATE____________________

AMBIENT TEMPERATURE____________________

BAROMETRIC PRESSURE____________________

GENERAL INFORMATION FOR THIS INSTRUMENT:

Mnaufacturer:____________________

Type:____________________

Intended Use:____________________

Readout Device:____________________

Certifying Technician:____________________

Certified Pressure Range:____________________

Minimum Allowable Reading(Readability):____________________

Minimum Allowable Reading(Calibration):____________________

Dummy Calibration Resistance:__________52

Dummy Calibration Pressure __________bar

FROM THE REFERENCE STANDARD CERTIFICATE:

Type:____________________

Calibration Agency:____________________

Certificate Expiration Date:____________________

Ambient Temperature:____________________

Barometric Pressure:____________________

Comments:____________________

VERIFICATION DATA:

Date	Technician	Deviation

True Reverence Value	Trial 1 Indicated Value	Trial 1 Deviation	Trial 2 Indicated Value	Trial 2 Deviation		Maximum Deviation	Average Deviation	Spread	Spread Ratio	Average Indicated Value	CORRECTION: Add To Indicated Value

SAMPLE CORRECTION CHART

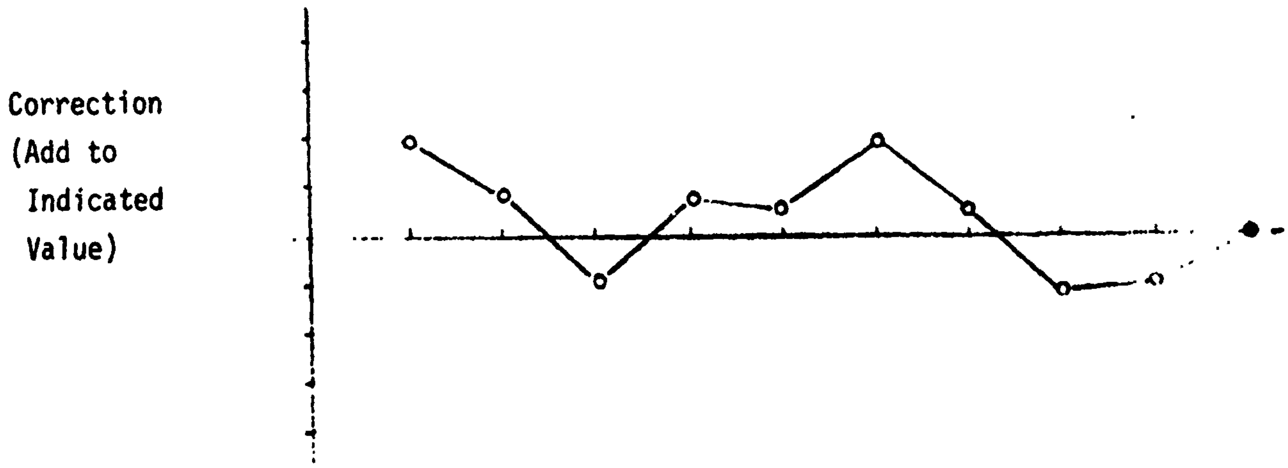


Figure 2.7.4.8.9.1

2.7.4.8.9.1 If the correction option is used, then the formula for Minimum Allowable Reading in Step 2.7.4.8.5 applies.

2.7.4.8.10 If the correction option is not used, then the Minimum Allowable Reading (MAR) is the largest value found by applying the formula:

$$MAR = \frac{|\text{Maximum Deviation}|}{EC(A/B/C)}$$

to each row of Chart 2.7.4.8, where EC is the Error Contribution due to Calibration and is based upon accuracy class:

EC(A) = 0.0005
EC(B) = 0.001
EC(C) = 0.0025 .

2.7.5 Verification of the Working Instrument

2.7.5.1 The Calibration of the Working Instrument shall be verified periodically in accordance with the requirements of Table 2.5.1.

2.7.5.2 The procedure and requirements for verification shall conform to Clauses 2.7.1, 2.7.2, 2.7.3, and 2.7.4, but with the exception that Certificate shall not be issued, rather the existing Certificate shall be initiated by the technician and other data recorded in the Verification Section of the Certificate.

2.7.5.3 If the Working Instrument is equipped with a Dummy Calibration feature, such as shunt resistor calibration in strain gauge transducers, then prepare the instrument by zeroing the Readout Device with zero input pressure and setting the span during dummy calibration to agree with the value on the Certificate. Recheck zero and the calibration point until no refinement of either adjustment is needed to achieve repeatability. Treat the Working Instrument as if it had no zero or span adjustments through out the remainder of the verification.

2.7.5.4 Upon completion of the Vertification per Clause 2.7.4, determine the Deviation by calculating the difference between the single Indicated Value obtained in Verification at the Minimum Allowable Reading and the Average Indicated Value obtained during Certification at the Minimum Allowable Reading, and dividing by the Average Indicated Value. The Deviation shall not exceed the applicable value from Table 2.5.1. Failure to conform shall constitute immediate cause for re-certification.

2.8.0 Pressure Taps

2.8.1 Determination of Tap Hole Quality

2.8.1.1 Select the class of measurement to be used (A/B/C).

2.8.1.2 Select the lowest pressure desired (Minimum Allowable Reading) to be measured in the class of measurement selected in 2.8.1.1.

2.8.1.3 By calculation, determine the approximate velocity of the fluid at the point in the system where pressure is to be measured.

2.8.1.4 Calculate V' = (velocity from 2.8.1.3)(specific gravity of the fluid).

2.8.1.5 On Figure 2.8, determine the point of intersection of the above pressure and V'. If the point falls below the line ($A_T/B_T/C_T$) for the class of measurement selected in 2.8.1.1, the tap hole quality is not important and any method of tapping into the pressure line can be used as long as it does not reduce the cross-sectional area of the pipe more than 5%. Note: The location of the pressure tap should still be in conformance with the individual component test procedures. If the point falls above the respective class line ($A_T/B_T/C_T$) and it is desired to keep the same measurement class, velocity and Minimum Allowable Reading, an improved pressure tap hole will have to be used.

2.8.2 Improved Pressure Tap Holes

2.8.2.1 Improved pressure tap holes fall into two catagories:

1. unverified
2. verified

Both types are identical in construction, but a penalty is imposed in Figure 2.8 for not verifying an improved tap hole. However, even with this penalty, unless extreme accuracy is required, the unverified tap hole should serve most fluid power pressure measurement situations.

2.8.2.2 Unverified Tap Hole Construction

2.8.2.2.1 Hole dimension criteria
The pressure tap hole shall extend from the fluid side of the pipe wall for a minimum of 1.5 times its diameter before its dimensions or shape is altered (Figure 2.8.2.2.1).

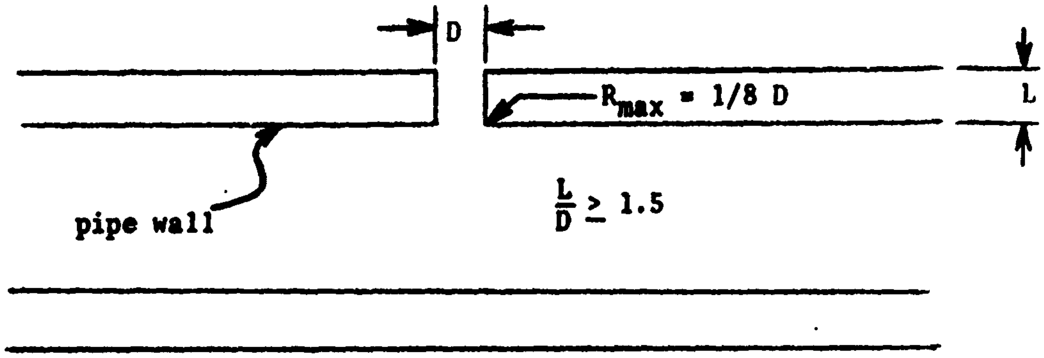


FIGURE 2.8.2.2.1

2.8.2.2.2 Deburring
The tap hole shall be deburred through the use of any or all of the following methods until the hole is flush with the inside of the pipe wall and no burrs on the inside of the pipe wall can be observed or felt.

1. Reaming of the tap hole.
2. Use of a small deburring tool through the tap hole.
3. Use of a deburring tool from the open end of the pipe or tube.
4. Honing of the inside of the pipe wall with a honing or similar tool.
5. Use of a deburring tool accessed through another hole drilled 180° from the tap hole.

Care should be taken not to create a radius greater than 0.2 D of the tap hole at the point where it meets the inside of the pipe wall.

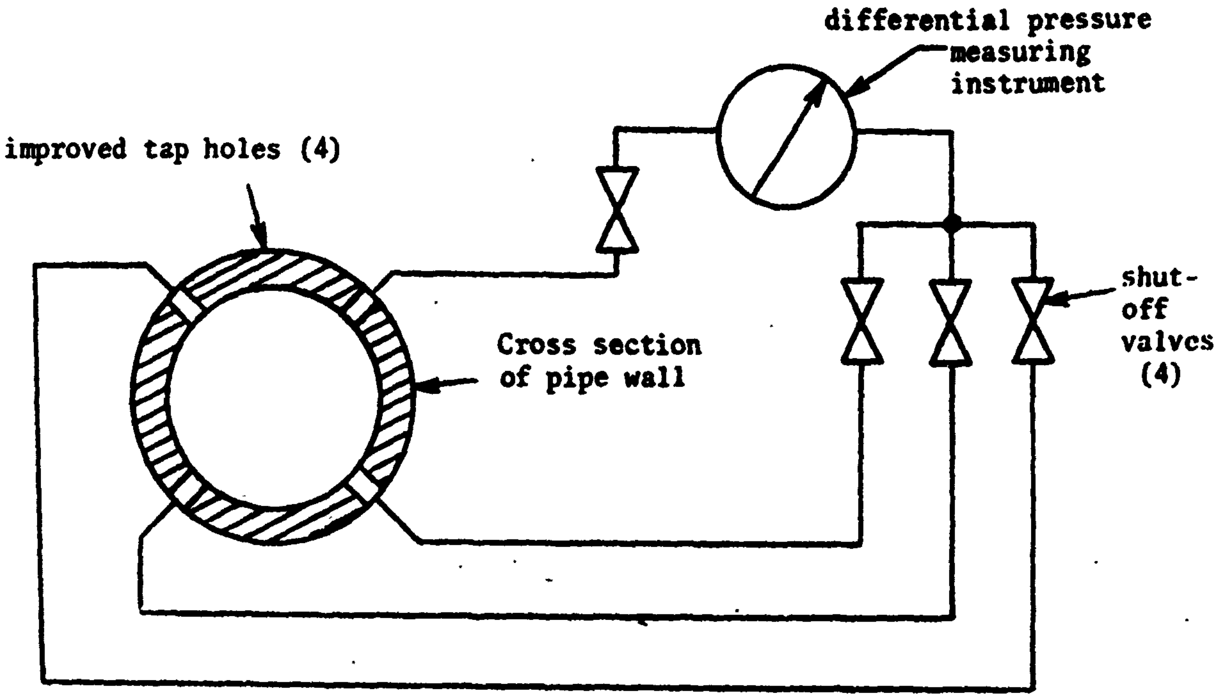
2.8.2.2.3 Tap Hole Connection
Any method can be used to adapt the tap hole to a conventional fitting as long as it does not violate Sections 2.8.2.2.1 and 2.8.2.2.2.

2.8.2.3 Use of the Unverified Tap hole
Referring to Figure 2.8, determine if the point of intersection of the Minimum Allowable Reading and V' used in Section 2.8.1 falls below the selected calss of measurement line ($A_p/B_p/C_p$). If it does, the tap can be used for any pressure measurement at or above the Minimum Allowable Reading and with velocities at or below those selected in 2.8.1. If the point of interception falls above the selected class line ($A_p/B_p/C_p$), a verified pressure tap hole must be used.

2.8.2.4 Verified Pressure Tap Hole Construction
The construction methods for the verified tap hole are the same as those listed in Section 2.8.2.2 for the unverified hole, with the exception that 4 holes are placed in the pipe in such a manner as there are 2 pairs of holes, each hole in a pair placed 180° from the other.

2.8.2.5 Verified Pressure Tap Hole Verification

2.8.2.5.1 Plumb the 4 pressure tap holes to a pressure measuring instrument in such a manner that one hole is used as a reference and the differential pressure can be measured between it and the other 3 holes as in Figure 2.8.2.5.1.: Figure 2.8.2.5.1:



2.8.2.5.2 Verify that the pressure measuring instrument reads zero differential between all taps while the pipe is filled, but no fluid is passing through it.

2.8.2.5.3 Pass fluid through the pressure tap pipe at the same velocity (± 5%) as it will be used during the specific component test. If the verified pressure tap is to be used over varying fluid velocities, pass fluid through it at the minimum velocity and in 25% increments up to and including the maximum velocity.

2.8.2.5.4 Record the differential pressures between the reference tap and the other 3 tap holes at each of the above velocities.

2.8.2.5.5 Calculate the maximum differential pressure between any of the 4 tap holes at each fluid velocity. (Tap Differential).

2.8.2.5.6 If the verification fluid has a different specific gravity than the test fluid, correct the Tap Differential obtained in 2.8.2.5.4 by the following relationship:

$$(TD)_{corrected} = (TD)_{measured}\left(\frac{\text{S.G. Test Fluid}}{\text{S.G. Verification Fluid}}\right)$$

2.8.2.5.7 The Minimum Allowable Reading that the verified pressure tap can be used at for a specific velocity (V_X) and class of measurement is obtained using the expression:

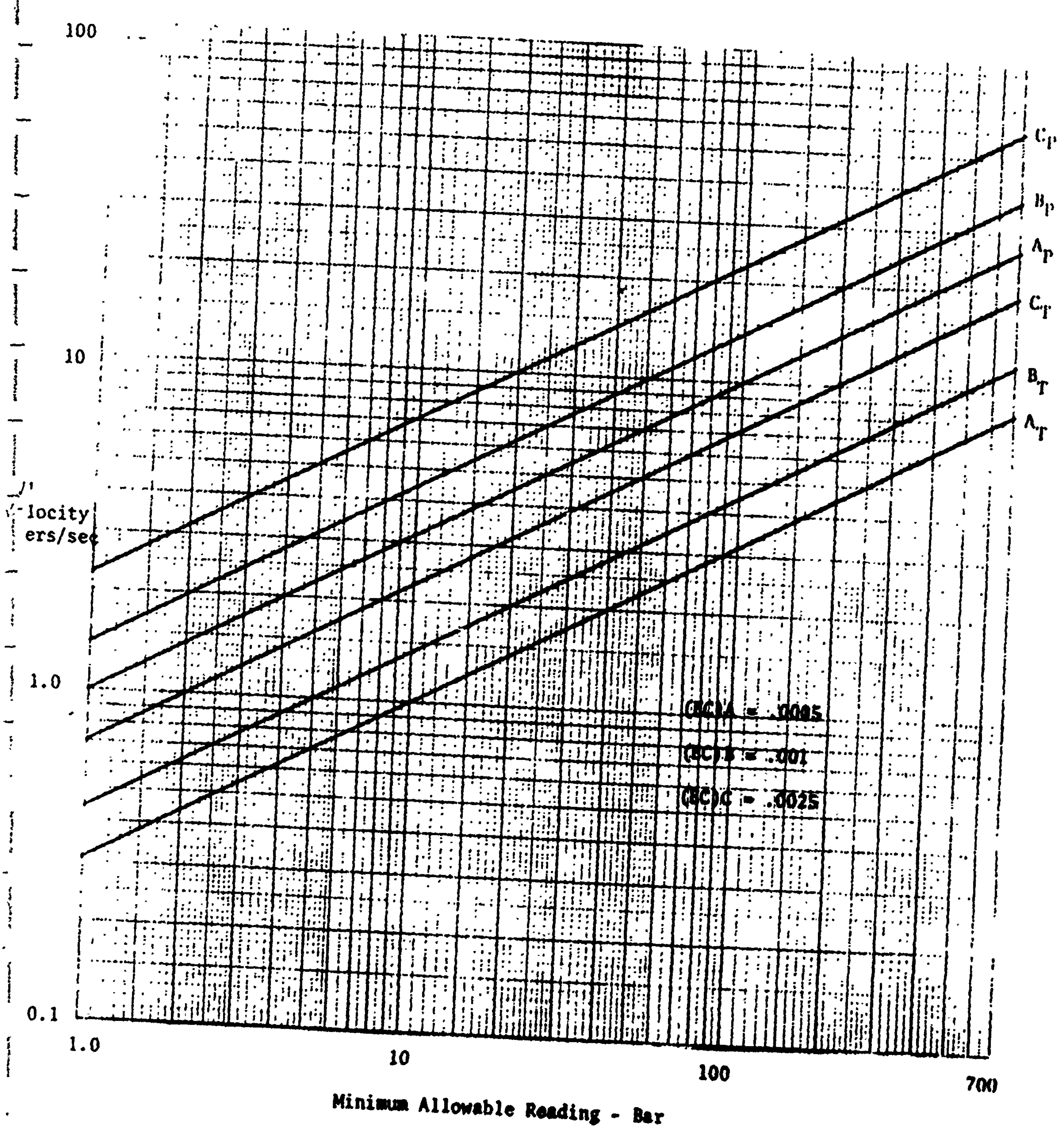
$$(MAR)_{V_X} = \frac{(TD)V_X}{EC(A/B/C)}$$

If the verified tap is to be used at various velocities, plot the 5 Minimum Allowable Readings obtained for it vs. the respective velocities V_1 ... V_5 on log-log paper in the same manner as Figure 2.8. Draw a best-fit straight line through the 5 points. If the velocity and pressure point that the verified tap is to be used at falls below the line, the verified tap can be used to collect data. If the point falls above the line, the tap holes must be further improved and reverified according to Sections 2.8.2.2 and 2.8.2.5.

2.8.2.6 Use of the Verified Tap

Although the verification procedure requires 4 tap holes to be constructed in the pipe, not more than one of the tap holes is to be used per measuring instrument. The tap holes are <u>not</u> to be connected together in a piezometer ring.

Figure 2.8



100
10
1.0
0.1
locity
ers/se
C_P
B_P
A_P
C_T
B_T
A_T
(BC)A = .0005
(BC)B = .001
(BC)C = .0025
1.0
10
100
700
Minimum Allowable Reading - Bar

2.9.0 Requirements of Snubbers

2.9.1 Snubbers may be of either fixed or variable (adjustable) type.

2.9.2 Qualifications of Snubbers

2.9.2.1 A snubber shall qualify for use in a class C Measurement Situation if upon inspection of a cut-away drawing showing that the forward and reverse flow parths are symmetrical.

2.9.2.2 Other snubbers shall be qualified only if their use is constrained to the operating region below the applicable line in Figure 2.9.2.2 when the symmetry ratio, ρ, is evaluated in conformance with this standard.

2.9.2.3 Evaluation of the Symmetry Ratio

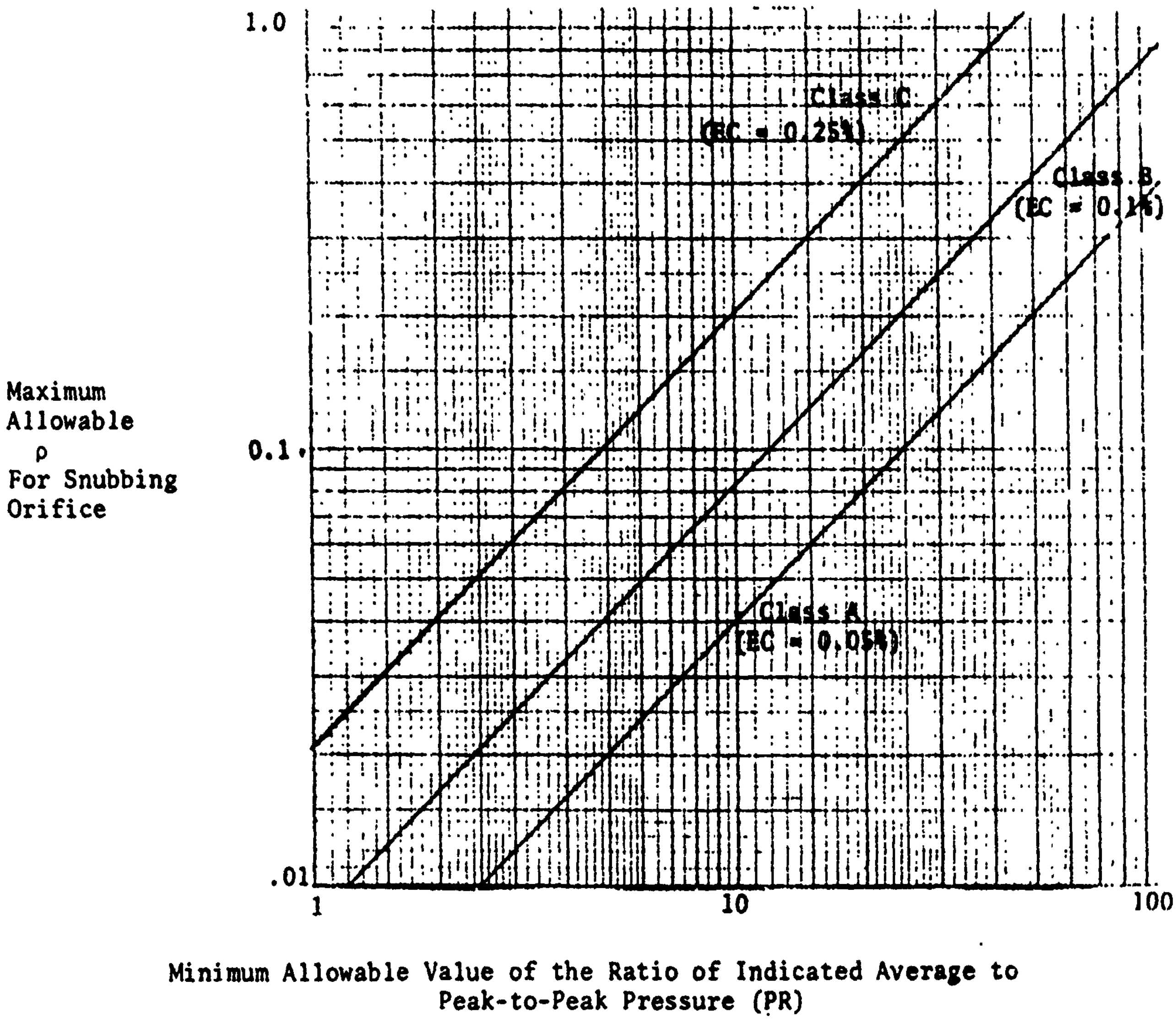
2.9.2.3.1 The Symmetry Ratio can be expected to change with a change in the adjustment of a variable snubber, therefore, the approximate setting must be established first. Also, it is necessary to determine the approximate peak-to-peak amplitude of the pressure pulsation to be damped.

Install the snubber and Working Instrument in a pulsating pressure line similar to or the same as the one to be tested and adjust the snubber for the desired degree of damping. Using a pressure transducer and Readout Device which have been calibrated in accordance with Class C accuracy requirements, determine the peak-to-peak amplitude of the pressure pulsations.

Use this setting of the snubber adjustment as a starting point during the pressure-flow tests and use the peak-to-peak pressure thus found as a guideline in establishing the maximum test pressure in the pressure-flow tests. Note or mark on the body of the snubber the forward flow direction which is arbitrary, if the snubber is not previously marked.

2.9.2.3.2 Without disturbing the setting established in 2.9.2.3.1, install the snubber in a test system which can supply test pressures up to at least one-half the peak-to-peak pressure found in 2.9.2.3.1. (Note: The maximum pressure used in the Symmetry Test dictates the maximum peak-to-peak pressure for which the snubber is qualified during the Measurement Situation).

2.9.2.3.3 Record pressure, flow, and fluid temperature data for ten pressure levels up to the maximum pressure for which qualification is desired. (Note: Peak-to-peak pressures of up to 100 bar in hydraulic systems are not unusual, necessitating snubber qualification up to 50 bar). The absolute accuracy of the flow and pressure measurements is not critical, since the purpose of the test is to compare the



Snubber Forward to Reverse Symmetry Criteria

Based upon .05%, 0.1%, and 0.25% of reading

Error contributions. $\rho = 0.08285 \times EC \times PR$

where EC is expressed as a percent.

FIGURE 2.9.2.2.9

2.10.0 The Measurement Situation

2.10.1 General Set-Up

2.10.1.1 Take the necessary precautions to protect personnel and equipment during both set-up and testing.

2.10.1.2 Set up the Working Instrument in accordance with the manufacturers' recommendations, but modified by any notations on the Certificate and connect the Working Instrument to a pressure tap which has been machined and/or evaluated in conformance with Clause 2.8.0, and which has been installed in the test circuit in a location dictated by the appropriate component or system test procedure standard. Bleed all instrumentation lines of entrapped air up the hydraulic fitting on the Working Instrument. If the Working Instrument is equipped with a bleed feature, bleed at that point.

2.10.1.3 Length of interconnecting line between the pressure tap and the Working Instrument shall not be less than 25 cm in order to help create temperature isolation for the Working Instrument.

2.10.1.4 The ambient temperature of the Working Instrument shall conform to the temperature at which the Working Instrument was calibrated within the following limits:

Class A $\pm$ 10°C
Class B $\pm$ 25°C
Class C $\pm$ 50°C

Employ dummy calibration often to verify or re-set the span adjustment before each use on any electronic instruments so equipped.

2.10.2 Use of Snubbers

2.10.2.1 The preferred position of the snubber is as close to the pressure tap as is practical in order to take advantage of the line and Working Instrument hydraulic capacitance to facilitate damping of pressure pulsations.

2.10.2.2 Verify conformance with Clause 2.9.0 by measuring the peak-to-peak pressure pulsations within $\pm$ 10% with a pressure transducer installed in the inlet line of the snubber, but with not more than 25 cm total line length between snubber and transducer. The transducer may be connected to the snubber line with a commercially available "Tee" fitting. The Transducer and Readout Device shall be any which have been Calibrated to conform to Class C accuracy requirements and which are claimed by their respective manufacturers to have frequency responses at least ten times greater than the fundamental frequency of the pressure pulsations.

2.10.2.3 It is recommended that lengths of interconnecting lines between tap and snubber not be integer multiples of one-quarter wavelength of the fundamental frequency; half wavelengths are preferred. The wavelength can be estimated in hydraulic oils from the formula:

$$\lambda = \frac{C}{f}$$

where C is approximately 110 cm/sec and f is the fundamental frequency.

2.10.2.4 While the test system is in operation, adjust the snubber until the pointer on an analog Readout Device fluctuates an amount less than the smallest scale division. Estimate the actual value as being the mid-point of the limits of oscillation.

2.10.3 Acquiring Data

2.10.3.1 Take readings only after the measurement system and the tested system reach steady-state.

2.10.3.2 Correct each reading using the Correction Chart developed during Calibration of the Working Instrument if that option is employed.

2.10.3.3 Correct all the Indicated Values for fluid head pressure caused by a difference in elevation between the Working Instrument and the pressure tap when the head exceeds the applicable following percent of Indicated Value:

Class A $\pm 0.05\%$
Class B $\pm 0.1\%$
Class C $\pm 0.5\%$

To calculate the correction, use the formula:

$$\delta P = \rho h \times 10^{-5}$$

where δP is the pressure correction, ρ is the density in newton/cm^3 and h is the height that the Working Instrument is above the pressure tap. ρ can be taken from the fluid manufacturers' data and h can be estimated within 10%.

2.10.3.4 Certified Pressure Readings shall be defined as those taken with instruments and procedures which meet all applicable requirements of this standard.

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